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NATIONAL SCIENCE AND TECHNOLOGY POLICY

HEARINGS

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

ON

NATIONAL SCIENCE AND TECHNOLOGY POLICY; NATIONAL NEEDS, MAJOR CHOICES, EMERGING PRIORITIES, AND MAJOR INSTITUTIONS

SEPTEMBER 28 AND 29, 1989

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NATIONAL SCIENCE AND TECHNOLOGY POLICY

THURSDAY, SEPTEMBER 28, 1989

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:35 a.m., in room SR-253, Russell Senate Office Building, Hon. Albert Gore, Jr. (chairman of the subcommittee) presiding.

Staff members assigned to these hearings: Pat Windham and Mike Nelson, professional staff members; and Fiona Branton, minority staff counsel.

OPENING STATEMENT OF HON. ALBERT GORE

Senator GORE. The hearing will come to order. We are going to get started on time. I had hoped to visit personally with our witnesses before we begin, but we may have a vote at 10:00 a.m. We have a lot of ground to cover today, and it is best to get started.

This is the first of two Science Subcommittee hearings on national science and technology policy. We all know that science and technology is going to play a key role in our ability to address many of our Nation's difficult challenges. The purpose of today's hearing is to ask whether those challenges and the country's needs have changed during the past decade and, if so, how our national policy toward science and technology ought to be updated and changed to enhance our ability to respond.

I am convinced that the challenges we face have in fact changed a great deal. I do not want to prejudge what we are going to find in these hearings, but I think that much at least is self-evident. Our country now faces unprecedented new challenges, and science and technology policy must respond to them.

This morning, among other things, I want to explore four major challenges that the United States now faces and will face during the 1990s and beyond: increased foreign economic competition; a new dependence of our military strength on civilian technology; the sharp mismatch between the skills required by high tech jobs and the skills our young people receive; and the unprecedented threat now facing the global environment which is posing a threat to the health and well-being of our species and our planet.

We have many other problems as well. We are going to address many of them, but we are going to look at these four first of all.

This morning I also want to examine the major policy choices, including budget choices, that Congress will face during the 1990s where science and technology are concerned. There are many changes but limited funds. We must make wise decisions on the use of Federal research funds and the design of Federal science and technology programs. We must find innovative ways to use limited resources to meet pressing national needs.

These discussions will continue tomorrow during a second day of hearings, and tomorrow's hearing will focus on the new science and technology priorities that are now emerging and the institutions that Americans use to make and implement that policy.

Among other witnesses, tomorrow we will hear from three former presidential science advisors and the Director of the National Science Foundation.

These two days of hearings are part of this subcommittee's continuing work to identify today's major science and technology issues and help to shape our national policy in this area. We intend to stay extremely active in this particular field. There will be further hearings on this general subject and specific components of the general subject in the months ahead.

In fact, it is my hope that these two days of hearings will set the stage for a continuing and constructive dialogue with the scientific community and Dr. Bromley, the new Director of the White House Office of Science and Technology Policy.

I have announced a tentative plan to ask Dr. Bromley to return to the subcommittee hearing table as soon as he selects the four assistants he has indicated he will soon ask the President to nominate. As part of the confirmation process for those four individuals, our subcommittee intends to have all four of them come simultaneously with Dr. Bromley. In questioning them in some significant depth, we hope to use the record of these two days worth of hearings on science and technology policy as the base for those questions.

This morning we have a very distinguished set of witnesses. I am very grateful to them for sharing their expertise with us and getting these hearings off to a good start.

Before turning to our first panel, I would like to recognize the Senator from Virginia, Senator Robb.

Senator ROBB. Mr. Chairman, I have no opening statement. Thank you.

Senator GORE. All right.

I have opening statements for the record from Senators Hollings, Rockefeller, Pressler, and Kasten.

[The statements follow:]

OPENING STATEMENT BY THE CHAIRMAN

These hearings on national science and technology policy are being held at a critical time. Technological change, political change, and economic change, both at home and abroad, are forcing us to reassess Federal science policies and priorities. Concerns about competitiveness, questions about our military technology, growing environmental problems, and forecasts of coming shortages of technical manpower have me and a lot of people worried. Luckily, we have some renowned witnesses here today to help us examine these problems and hunt for solutions.

Our current problems are deep and serious. Take competitiveness as an example. In the last three years, competitiveness has become a major national issue. It will certainly be near the top of the agenda today. Each day we hear new stories of Japanese advances or the challenge of Europe–1992. For instance, on Tuesday we saw articles on Sony's bid to buy Columbia Pictures for $3.4 billion, in cash. (The Japanese don't have to use junk bonds.)

That is just the latest symptom of the United States' trade deficit with Japan. Last year, that deficit ran over $50 billion dollars, and this year it will be much the same. The Japanese are out-competing us, making lots of money, and using their earnings to make billions more. In order to shrink the trade deficit and regain our competitive edge, we need to maintain the strong technological base that we've built over the last fifty years and use it more effectively to make better products for the world market.

The United States government has invested billions of dollars in research over the years. The result is a large reservoir of scientific and technical talent and research institutions that are the envy of the world. Even the Japanese would like to have an MIT or a JPL.

However, we need to maintain and expand that technological base. We cannot just win Nobel Prizes, we have to also win foreign markets for American products. That requires not just research scientists in the labs, but world-class engineers in our factories. New discoveries from the lab need to be put to use quickly if we are to beat the foreign competition. Keeping American competitive will require science and technology policies that both maintain our research labs, where new ideas are born, and improve and expand our industrial labs, where there ideas are turned into products and profits. We must have both.

The Commerce Committee has taken a lead in this area and recently approved my legislation, S. 1191, which would start important new technology programs at the Department of Commerce. It would increase funding for the National Institute for Standards and Technology (NIST), so that NIST could expand its support of American industry. The bill would provide funding for critically-needed in-house research at NIST in HDTV, superconductivity, advanced semiconductors, fiber optics, biotechnology, and other technologies for the 1990's and beyond. In addition, S. 1191 authorizes $100 million for the Advanced Technology Program which would fund industry-led research projects in many of these same areas.

To speed up technology transfer, the Omnibus Trade and Competitiveness Act of 1988 already provides FY 1990 authorizations for NIST's new Regional Centers for the Transfer of Manufacturing Technology, which show small- and medium-sized firms how to use new technology to improve their manufacturing and thus improve their profits. Three centers were created at the end of 1998, and I hope will see three more established within the next year. Initiatives like these are essential if American is going to stay in the high-tech game.

There are signs that the Bush Administration is starting to recognize this point. President Bush has brought some very talented people abroad who understand both technology and business, including Secretary of Commerce Mosbacher, Deputy Secretary Tom Murrin, and the new Science Advisor, Dr. Allan Bromley. This Congress and this Administration have a chance to ensure that American science and technology policy will keep the United States from becoming an economic also-ran.

That means accelerating technology transfer; that means continued strong support for basic research; that means educating more American scientists and engineers.

Science and technology policy was once a obscure topic left to a small handful of experts. But science and technology policy has become more and more important and more and increasingly intertwined with economic policy, our defense stance, and environmental protection. Clearly, a crumbling technology base will adversely impact our nation's ability to response to the urgent challenges we face.

Fiscal policy and our budget deficits are certainly impacting America's science policy. Budget deficits mean higher interest rates and less corporate investment in long-term R&D. And it is hard to increase Federal R&D funding without taking care of our budget mess. We need to wake up; foreign countries are dramatically increasingly their investment in research and development, while we are arguing about ways to cut taxes as the deficit just keeps growing. Remember, when Mr. Bush says, "No new taxes" he is also saying "No new research" and down the road that means, "No new jobs."

I know that today's hearing will highlight some of the problems with American science and technology. Fortunately, there is a growing consensus that science and technology is one of the best investments that the Federal Government can make. Ours is not a poor country; we can make this investment. And we must, because if we do not, America could lose its way, and its future, and become a second-rate economic and military power. I, for one, am working hard to prevent that.

Opening Statement by Senator Rockefeller

Mr. Chairman, I commend you for these two days of hearings on national science and technology policy. The energy and activity that you have brought to this subcommittee have helped focus attention on a range of science and tech issues—and I am extremely pleased to see that

The purpose of these hearings is not to study a specific piece of legislation, but rather to take a big picture, long-term view of science and technology policy. As we approach the 1990s, it's critical that policymakers sit down together to carefully examine how science and technology can be used to help us meet future challenges—be it global change, international economic and technological competitiveness, or an altered national security situation.

We, in Congress—and more specifically this subcommittee, as the Senate subcommittee with explicit science and technology jurisdiction—have a responsibility to determine how existing science and technology programs should be modified to meet these major challenges.

This morning, we are extremely fortunate to have before us the leadership of the science and technology policy world. It's a tremendous opportunity for this subcommittee to have three former Presidential science advisors, a Nobel laureate (Herb Simon), and the Director of the National Science Foundation all in one room. We should take full advantage of this opportunity.

I would like to leave here today with a fuller understanding of what should be the nation's priorities among the many science and technology projects that come before the Congress. In a time of limited resources, where would you—the experts—put our federal dollars? Frank Press has been an outstanding leader in this area and I applaud him for the guidance he has given us.

I also would like to hear from all of you about our nation's science and technology infrastructure and how well-suited it is to the changes we expect to see in the next decade. What role should the Office of Science and Technology Policy play? Do we need one centralized science and technology agency?

As a country, we will be facing unprecedented challenges as we head into the next century. Inevitably, Congress will be called upon to make major policy choices, many of them on science and policy issues.

Dr. Bromley, at his nomination hearing, talked about his willingness to engage in an informal dialogue with members of Congress about the policy issues we are faced with. As non-scientists, we would welcome—and need—your help. I hope that all of you will be active and candid participants in that dialogue.

Thank you, Mr. Chairman.

Opening Statement by Senator Pressler

Thank you, Mr. Chairman, for calling this hearing to address science and technology priorities, and how Federal science and technology policy can be used to meet the nation's changing environmental, education, economic, and national security.

Federal science and technology policy can make an immense difference in our economy and in our national defense readiness. Technology is responsible for 80 percent of the country's productivity growth since the Depression. But now we hear almost every day that the United States is losing economic leadership to foreign nations, and that we are in danger of becoming a second-class economy. What can Federal science and technology policy do to eliminate that possibility?

We need to make the best use of the R&D resources that are available. For example, NASA's Earth Observing System (EOS) will soon be providing a large amount of data on the earth's environment. The land remote sensing data acquired by EOS will be stored at the EROS Data Center in Sioux Falls, South Dakota. This data will significantly improve our ability to predict and react to changes in our climate and environment. This program is just one example of the practical application of science and technology to solve real problems that we are facing in this country.

But we cannot capitalize on our valuable science and technology resources without a well educated population. We need to make sure that everyone in the United States has access to a quality education, and that we have qualified teachers to educate our students. To really benefit from science and technology, and all that it has to offer, we have to especially encourage students at all levels, from grade school through college, to go into science, mathematics, and engineering. Human resources are the most important resources we have. We must make sure we are doing what we can to develop those resources, and put them to their best possible use. That has to be one of our top priorities.

We in Congress are facing difficult research and development funding decisions. Should we build the superconducting supercollider? The space station? The National Aerospace Plane? Should we develop a map of the human genome? Should we appropriate more funds for the National Science Foundation, and should those funds include money for new university facilities? Given all of these important projects, how can we make sure we get the best for our limited resources? I hope the distinguished witnesses we have today and tomorrow can help us focus on some of these important issues.

OPENING STATEMENT BY SENATOR KASTEN

Mr. Chairman, I am pleased that you are holding these hearings today and tomorrow on the current state and future needs of our national science and technology policy.

We are in the middle of this year's round of Appropriations bills and we have seen, as Senators Garn and Mukulski pointed out in managing the HUD and Independent Agencies bill, that monies for such "big science" projects as Mission to Planet Earth and the Space Station yield to the apparently more pressing needs of the immediate present.

But as we all know, these longer term projects and investments are necessary for the continued vitality of this country, and its ability to compete and live with a quality environment. With the 12 agencies in the executive branch, and 9 Congressional Subcommittees, involved in directing the spending on civilian R&D, coordination of overall policy is an issue that we must look into.

As we look to the necessary role that we expect out science and technology sectors to play in maintaining, and in some areas regaining, America's competitive edge we find the inter-relationships with so many other areas, such as education, job training for the new skills required, and the proper role for government participation with the private sector in R&D and other areas, including industrial development.

I look forward to this set of hearings and working with the Subcommittee in developing the appropriate mechanisms that can assist us in managing and supporting this country's substantial science and technology efforts.

Senator **GORE**. Our first panel is made up of: Dr. Lewis Branscomb, Director of the Science, Technology and Public Policy Program at the John F. Kennedy School of Government at Harvard; Dr. Donald M. Langenberg, President-Elect of the American Association for the Advancement of Science at the University of Illinois at Chicago; Dr. Robert Costello, Senior Fellow with the Hudson Institute in Indianapolis, Indiana; and Dr. Richard Anthes, President of the University Corporation for Atmospheric Research in Boulder, Colorado.

Dr. Branscomb, you are our lead-off witness.

I want to also note for the record that Dr. Branscomb is a Tennessean. You know, the combination of Tennessee and Harvard is just really outstanding. That is not the only reason you are our lead-off witness, but we certainly appreciate your presence here.

STATEMENT OF LEWIS M. BRANSCOMB, DIRECTOR, SCIENCE, TECHNOLOGY, AND PUBLIC POLICY PROGRAM, JOHN F. KENNEDY SCHOOL OF GOVERNMENT, HARVARD UNIVERSITY

Dr. **BRANSCOMB**. Thank you very much, Senator. It has been a pleasure for me the last three years to bring some Tennessee wisdom to Harvard University.

If I may, I would like to hit the high points of my statement, which is a more complete survey of science and technology policy issues than there is time for us to cover today. Let me start with some comments about how circumstances have changed and then get to what I believe should be the agenda for serious debate on these matters.

The place to start is the recognition that the United States has never had an explicit science and technology policy or even an institutional process for creating one, and that is not all bad.

First of all, 70 percent of the R&D in this country is performed in private industry, and half of it is paid for there. So any national policy must include the views and strategies of the private sector.

Second, since World War II our government's policy has focused really on the creation of knowledge and the creation of technology and some major government programs largely for public purposes rather than on the diffusion of technology and its use. As I will say later, I think we need to change the balance in that ratio for good reason.

The *de facto* policy has featured a high degree of decentralization of decisions about science and technology. That, too, is a strength, because it has allowed us to have a competitive intellectual marketplace, and we drive our science by that process rather than by bureaucratic decision.

By directing each agency of government and each firm to take responsibility for putting back into the knowledge pool in proportion as they draw from it, we created a research and innovation tradition built into the fabric of our society. That is probably the strongest argument made by those who oppose the idea of collecting all Federal activities together into a Department of Science.

Because of the low savings rate, excessive consumption, and the reluctance to increase revenues to face our needs, we do of course face serious resource pressures, both in the government and the firms. Yet R&D appropriations are not centrally budgeted, in the context of this decentralized policy.

I think we will in the future have to be more hardminded about the tradeoffs and especially to think hard about the nature of the technological and/or scientific benefits that we get from big government-funded technology projects. It is not that those projects are not justified, but we need to think through the mechanism whereby they bring benefits and to try to put those benefits in scale and perspective.

I do not need to reiterate how the circumstances of the United States have changed economically or how the bipolar political situation we have had since World War II now is becoming a multipolar one. By and large American greet that with some enthusiasm, but a consequence, of course, is that economic issues are an increasingly important part of national security perceptions.

We have become much more interdependent with our democratic allies and their economies. We have to view science policy problems as a global issue, not as a zero sum game and not as a strictly domestic U.S. political problem. That raises some issues we will have to deal with.

It is important to appreciate that the dominant source of change in the world today is growth, and the predominant source of that growth is technology. By growth I mean economic growth, population growth and, as a consequence, growth in serious environmental concerns.

Science and technology have fueled that growth, and they can also be the source of wisdom for deciding how to manage it and the source of technology with which to manage it. It is surely a crucial matter that we not doom science to the role of destroying our habitat but, instead, give it the job of preserving it. Government has a lot to do with how that can happen.

In your opening remarks you said that our national security is now increasingly dependent on commercial technology. Back in 1960, 80 percent of Federal R&D investment were spent on defense, and the government spent just about twice as much on R&D as the private sector. Since 1960 private sector R&D expense has grown 2.5 times faster than government R&D, and there emerged on the scene a worldwide high tech industry. Other countries that have been principal generators of technology, such as Germany and Japan, have invested relatively little in defense technology. If you look at the world collection of technological knowledge from which all enterprises and governments can draw, there has been a huge shift from technology dominated by American defense investment (along with the French and British) to one where the main body of knowledge is industrial.

That does not mean that there is a less important role for government to play. What it does mean is that the government has to spend more time worrying about how that science and technology system works, particularly in its industrial context, and to pay attention not only to research but, importantly, the diffusion mechanisms, the human resources and the infrastructure that cause that system to work effectively.

Driving this international interdependence in technology and driving high tech industry have been some very important changes in science and engineering. Unless we understand these changes, we are likely to manage our government science badly.

Perhaps the most important trend is the merging of science and engineering. The boundaries between these are becoming indistinct. If we look at the principal ingredients of competitiveness in private industry, they relate not to research, not even to innovation, but they relate to the quality, the market responsiveness, the cost and the end user services associated with commercial business.

That calls for downstream engineering activity—that is, not the R&D world but in that downstream world where the majority of the engineering activity is. Competitive firms no longer use this sort of linear model of innovation that is characteristic of military innovation. They now must inject science into the manufacturing processes, into the quality management, into design activities, as well as into the R&D part of the innovation process. So we have to stop thinking about R&D as being synonymous with the technology problem facing the country.

Finally, the capacity to generate technology sure does depend upon research and invention, but its effective use rests on education, efficient knowledge distribution, and the ability and motivation of institutions and firms to absorb and use technical knowledge. All of these capabilities I refer to as the knowledge infrastructure of our society.

In the past we have taken it very much for granted, at least in the recent past. But, those concerns should be high on our priority list.

And, finally, in terms of what has changed, I think we also must not lose sight of the fact that life has gotten a lot more complicated.

The issues that divide Americans increasingly involve complex scientific questions about which there is incomplete knowledge.

The result is we are accumulating a long list of questions that do not seem to yield to rational analysis. Sometimes there is not even a consensus on how the question should be asked and certainly no agreement on what rational means.

Let me just give you three examples that will be familiar. There are controversies about matters of human reproduction, life and death, another set of controversies about waste management, reactor safety, chemicals in agriculture and the environment.

Another set of issues concern the global climate change problem, where we not only have an incomplete research base, but inadequate international institutions for guiding intergovernmental consensus.

We have to work on the problem of how can we use expert knowledge in a way that will help generate public consensus and allow us to make public decisions that have public support.

Now, a few comments on more specific issues.

On the issue of diffusion-oriented policy, the balance between the emphasis on technology stimulation versus technology diffusion, scholars like Henry Ergas with the OECD, comparing science and technology strategies of different countries, have characterized the American, British and French strategy as a "mission-oriented" strategy in which technological vitality is driven by demonstrations of technology prowess through major national endeavors.

Countries like Germany, Switzerland, and Sweden, and to some extent Japan, have paid much more attention to the training of technicians, the diffusion of knowledge, the upgrading of skills of workers and programs to encourage the adoption of new process technology by firms, especially small firms. Such countries are said to have a "diffusion-oriented" strategy.

This committee has, in fact, begun the process of encouraging and authorizing the Commerce department to address diffusion strategies. They are very early in the experience, but technology diffusion really deserves support and attention by the business community and the Congress to be sure that we learn those lessons well.

Although at the federal level we are correctly very cautious about engaging in what people call "industrial policy", at the state level it is fair game to compete with other states to try to increase industrial development and employment. To that extent, industrial policy is alive and well in the states.

They are spending about a billion dollars on technology stimulation and industrial extension, and yet state strategies for technology policy play a very weak role in federal executive thinking, and I think that has to be changed.

The Defense Department and the defense industry base is a subject on which my colleagues and I have done a great deal of research. I have no time to go into that in detail now. I would rather respond to your questions.

But, I would like to make it clear that it is not at all obvious that the solution to U.S. competitiveness problems lies in trying to make the Defense Department and the commercial world look more like each other. They each have serious innovation problems. I think the Defense Department's innovation process is in worse trouble than that of the commercial sector, and so I am not sure what defense has to teach commercial industry.

They do, however, share a skill base and a technology base. But, if we think about creating, let us say, in the Commerce Department an agency analogous to DARPA in the Defense Department, I think we ought to think hard about whether that would work the same way it works in DARPA.

I have questions about that. I think it would really have to be done differently.

Let me go past the issue of human resources which do deserve a lot of attention and conclude with an one observation about the health of the science and technology enterprise.

We are now engaged in trying to find a balance between the delegation of responsibility to the scientific community, and the government's need to set priorities. As recommended by Vannevar Bush in *Science, The Endless Frontier,* the creation of the National Science Foundation involved a social compact between the government and the scientific community. The country said to the university research sector, "If you will engage in research on problems important to the nation, we acknowledge that you need to control the process for how you pick problems and how you work on them. We will not tell you how to do that from the federal level."

But, as government resources get squeezed and as technology gets more and more economically important, there is a very serious temptation in the Congress to try to find ways to "earmark" funds to particular destinations.

The scientific community has to understand that geographical equity is an important issue. The Congress has to communicate to its constituents why these investments are important and how they bear fruit.

But, the earmarking, if it gets out of hand—and it has been growing rapidly—could destroy this delicate comity that allows a competitive system for allocating research support among these nonprofit institutions.

Second is the issue of standards of conduct and integrity for science. This is an issue that frightens a lot of scientists, but it is clearly our responsibility as scientists to address those questions and to satisfy the concerns the public may have about it because if the peer review process breaks down as a mechanism for quality control, we can destroy science as fast as we destroy misconduct.

Finally, let me just conclude by saying before World War II the idea of public research being contracted out was thought of as immoral. Public research was carried out in public institutions.

What the Bush Report really represented was a major change in policy, namely, the privatization of research, and it was an extraordinarily wise policy.

Our problem now is that we have to find ways to keep the science strong, and yet the government has to look at more than R&D in order to get economic advantage from science and technology.

Government has to look at technology diffusion and infrastructure, including networks and information services. Government must look at strategic allocations of public investments to important areas of science and technology and find a way to do that without destroying the tremendous vitality that came from the government decision to decentralize decisions on research conduct down to firms and individuals. And I think that is the big challenge that we face. Thank you.

[The statement follows:]

STATEMENT OF LEWIS BRANSCOMB, PROFESSOR, JOHN F. KENNEDY SCHOOL OF GOVERNMENT, HARVARD UNIVERSITY

I appreciate the invitation to join in the committee's deliberations on science and technology policy, and to respond to the committee's proposition, which I believe is correct, that national needs have changed dramatically over the past decade. Thus my testimony will deal primarily with the nature of those changes and the issues they raise for the structure policies and programs of the federal government. I will not attempt to delve into specific issues, although I have dealt with a number of them in recent testimony to other committees and would be delighted to respond to requests for additional views.

I will first summarize the new circumstances facing this country, which I believe require fundamental changes in the way we think about science and technology policy. Then I will suggest how a number of initiatives taken by the Congress - or under consideration - fit into this different vision of our circumstances.

Absence of explicit S&T policy.

At the outset let us remember that the U.S. has never had an explicit national science and technology policy, nor even an institutional process for creating one. That is not all together a bad thing. First of all, any national policy must be based on the public interest as seen by both government and the private sector. Seventy percent of all R&D in this country is performed in private industry, and half of it is paid for from private (business) funds. As an empirical matter, of course, the U.S. does have a de facto policy. Since World War II government policy has focused on the creation of knowledge and technology, largely for public purposes, rather than on its diffusion.

The virtues of decentralized S&T responsibility

U.S. **de facto** policy has featured a high degree of decentralization of decisions about science and technology. This too is a strength, especially in basic science where resources are best allocated by a competitive intellectual market-place, not by bureaucratic decisions. At a time when scientific and technical world leadership was more important than technological efficiency and public resources were available both for major national projects - such as Apollo -and for a highly competitive scientific enterprise, these two policy principles: ambitious goals and decentralized implementation have been very successful for America.

By directing each agency of government and each firm to take responsibility for the research and human resource investments that best strengthen its share of the knowledge base, we build a research and innovation tradition into the fabric of the society. This is one of the strongest arguments against collecting all federal R&D activities together into a department of science.

The problem of resource allocation

Because of a low savings rate, excessive consumption in relation to growth, and a reluctance to increase federal revenues the U.S. faces serious resource pressures in government and firms face a high cost of capital. Both situations call for more attention to the investment strategy in science and technology. The federal budget process examines S&T priorities on an agency by agency basis, making trade-offs against non-R&D expenditures; R&D appropriations are not centrally budgeted, either by the executive or the Congress.

We need to be more hard-minded about the nature of the technological or scientific benefits we get from big, government-funded technology projects. There has to be a more effective mechanism for comparing the relative merits of such big projects, and we need to look to international collaboration as the best way to accomplish many of them.

Changing U.S. circumstances.

Changing circumstances do compel more attention to how the science and technology system of this country works, on what infrastructure and human resources it rests, and how vitality can be increased while doing a better job of allocating our scarce resources of talent. America has been an island of unique assets in the years after world war II. We must now manage our assets more carefully and pay more attention to helping both public and private institutions use them effectively.

S&T as engines of growth, itself the engine of change.

The dominant source of change in the world today is growth -economic growth, population growth, and as a consequence growth in serious environmental concerns. American science and technology have been the fuel for much of this growth. They are also our best hopes for managing it intelligently on a global scale. It would be a tragedy if we allowed short range vision, an obsession for consumption and a chauvinistic attitude toward international cooperation to doom science to destroying our habitat instead of its preservation.

Dominance of industrial over government technology worldwide.

Thus one of the most important changes in the last 20 years is the emergence, first in the U.S. and then in Europe and Japan of an international high-technology industry, whose total R&D efforts in many critical fields dwarf those of governments, and specifically dwarf those of the military. In 1960 military technology dominated private technology (6.0 B to 4.52 B). In that year 80 % of federal R&D investments were from Defense. If you include Atomic Energy and Space it was 93% in 1963.

Since that time the big change is the world-wide rise of private, high-tech commercial industry. From 1960 to 1987 civil industry funded R&D grew 2.5 times as fast as did military R&D. In Japan and Germany, with proportionately much smaller defense R&D budgets, private R&D totally dominates.

Thus military and space technology no longer are the dominant source of radical technological innovations, as they were before the late '60s. Today commercially significant innovations are **more** likely to come from the private sector, and are much **less** likely to be exclusive to the U.S.

Economic competitiveness and national security.

The sophistication of technology in the industrial democracies has been closely watched by communist nations, whose weakened economies are driving them to rethink not only their economic policies but political and security policies as well. Thus technological progress has helped to trigger political changes that are bringing about a more multi-polar, interdependent world.

The weakening of the cold-war and the evolution of healthy democracies with laissez faire economies have been goals of American policy since world war II. But we must think seriously about adjustments in our policies that better equip Americans to benefit from the new situation that we have worked so hard to bring about.

Americans are now joining publics in other industrial democracies in the belief that economic strength is a critical component of nation security, growing in importance compared to war-fighting capability. This conviction will continue to strengthen if the economies of communist nations continue to weaken, limiting their capacity for military investments and providing incentive for arms control negotiations.

But a multi-polar world is also an interdependent one, with linkages forged by the world markets for capital, for talent and technology. The globalization of technology is driven not only by the growth of international markets and transnational firms to address them, but by important changes in the capabilities of science and engineering.

Merging of science and engineering.

The innovation process in competitive commercial industry is quite different from the way government manages innovation in defense industry. R&D are still important but they are by no means the whole story. The partnership we need between government and industry must be based on different paradigms than those we are accustomed to in big government projects.

The practise of science and engineering are changing. As engineering and science tend to merge, science has become important in design, production and quality management, not just in R&D. Today engineers can more easily describe in computer simulations just how a design will work and can specify the production processes to build it. These computer programs can be used to drive a production line. The several steps in this process of innovation can be located far apart, even in different countries, since the information is represented in electronic form.

Importance of "down stream" science and engineering

Thus when we address competitiveness issues in U.S. science and technology policy we must address capabilities in "down stream" science and engineering and in the elements of the innovation process that follow the R&D phase. If science and engineering are merging, and a primary goal of policy is to strengthen the knowledge base and the human resources for "down stream" technology as well as research and invention, how well does the current set of agency goals and missions fit? I submit that we are beginning to tread new ground here, as evidence both by the new missions for NIST and the new programs in DARPA, both of which are intended to have effects beyond R&D.

Need for a globally defined strategy.

Thus we see the rise of vertically integrated but geographically widely distributed enterprises. As world trade rises faster than domestic economic growth in almost every country, interdependence rises. Foreign investors are investing in U.S. industrial assets, but U.S. capital investment abroad is also rising. We must learn to compete and cooperate with friendly nations at the same time.

It will be increasingly difficult to define what we mean by "competitiveness" of the U.S. economy. U.S. interests have to be defined on a global scale not only in national security but in the technologies supporting the world economy.

We Americans are great generators of technology, but we must overcome our tendency to ignore the work of others and pay more attention to the diffusion of technical knowledge, the effective use of it, and the vitality of the infrastructure that supports a knowledge-based economy.

Knowledge-based infrastructure for national goals.

The capacity to generate technology still depends on research and invention. But its effective use rests on education, efficient knowledge diffusion, and the ability and motivation of institutions to absorb and use technical knowledge. All these capabilities might be called the knowledge infrastructure of our society. In the past we largely took it for granted. Today these concerns should be at the top of our priority list for long-term public investment.

I have placed most of the emphasis on the technological component of economic and political change around the world.

These drive the big questions of military technology, of strategies to help U.S. industry become more competitive, and of global environmental problems.

Scientific issues and political decisions

But here at home there are other sources of change that call for better ways to deal with scientific and technical issues. As we continue to try to make governance more participatory, and public interest groups proliferate and grow in political influence, we find the issues that divide Americans increasingly involve complex scientific issues and areas of incomplete technical knowledge. The result is that we are accumulating a longer and longer list of questions that do not yield to "rational" analysis; sometimes there is no consensus on how the question should be posed, hence no agreement on what "rational" means.

Three examples will suffice to make the point:

The intensity of controversies over matters of reproduction, life and death, not only prevents agreement on rules for permitted medical practise in this country but also limits our assistance to developing countries seeking to manage the size and health of their populations.

Controversies over the disposal of radioactive waste, the safety of power reactors, the effect of chemicals in agriculture and the environment delays a consensus on how we will satisfy future energy needs, keep agriculture productive and manage solid waste.

An incomplete research agenda and inadequate international institutions for guiding intergovernmental consensus impose serious obstacles to dealing with global climate change in a responsible manner.

In all three cases there are genuine problems requiring careful attention. But in both cases the gulf between most of the technical experts and much of the public suggests that we have not found sufficiently effective ways of using expert knowledge for guiding public decisions that will be understood and supported by the public.

Levels of R&D investment

All analyses of the technological component of U.S. industrial competitiveness focus on inadequate attention to production processes, to characterization and use of materials, to quality management and willingness to use ideas of others. Many of these issues have little to do with R&D. But the U.S. cannot be complacent about its level of R&D investment either.

The fact is that 29 years ago - in 1960 - the U.S. spent a higher fraction of GNP on R&D than we do today. With our larger economy and large military commitment we do outspend the Japanese in R&D by 2.7 times. But as a percentage of the GNP, the non-military R&D investment of the U.S. is only 2/3 as large an investment as that of Japan. And of that residual a larger fraction of Japanese R&D is funded by and performed in industry where it contributes more to the economy.

* * *

This background brings me to an enumeration of the specific issues that the nation must address.

Science and Technology Policy

There is an emerging consensus that while industrial policy is a label that seems to carry negative connotations of government interference with capital markets or business decisions of firms, there is a need to address issues of **technology policy** at the federal level.

There are several unresolved big issues, each of which will be briefly discussed below:

(a) How can federal technology best contribute to industrial competitiveness? Are large engineering projects with very challenging goals effective drivers of basic industrial strength? Is a more diffusion oriented strategy, such as industrial extension programs in cooperation with the states a more effective strategy?

(b) What role does defense have in this task? Should defense contribute more directly to the national technology base, or should the strategy look to the industrial base to lower the cost and accelerate innovations in military technology?

(c) Is the historically passive role of the federal government toward science and engineering education - at all levels - the correct balance of state and federal responsibility, or is there need for more direct attention at the national level to issues of educational quality, curriculum reform, and worker retraining?

(d) What are the most critical issues of technological infrastructure and services required to increase the productivity of U.S. science and technology?

(e) Within the domain of research that is appropriate for federal support, how can a research strategy be defined, across the agencies, that addresses the most important research needs for the national technology base? Does this require a change in the way government categorizes its S&T activities for budget and statistical purposes?

(f) How can we deal with threats to the health of the scientific interprise arising from the political temptation to "earmark" funds for specific institutions and from public concerns about misconduct in science?

g) Is federal regulation for health, safety and environment, together with adjudication of civil disputes in court the best way to accelerate scientific knowledge and technological solutions to these problems?

A diffusion-oriented policy.

On the first question a central issue is: what should the balance be between emphasis on technology stimulation through projects carried out in fulfillment of federal agency missions, versus emphasis on technology diffusion to workers and firms. Scholars, such as Henry Ergas, have observed that in the postwar US, the emphasis has been on "mission-oriented" technology policy in fulfillment of the U.S. leadership role internationally and in the absence of serious concerns about the technological competitiveness of firms and their workers. Countries like West Germany, Sweden and Switzerland, on the other hand, put much more emphasis on a "diffusion" oriented policy, emphasizing the training of technicians, upgrading skills of workers, and on programs to encourage adoption of new process technology by small firms.

Given the nature of modern industrial processes, it appears that much more emphasis should be given to such diffusion oriented policy. The new mission given to the National Institute for Standards and Technology in the 1988 Omnibus Trade Act, through the initiative of this committee, is an example of a serious, but still very modest beginning in this direction. This approach must receive much more serious attention at the federal level - and more uniform attention by the states.

Federal-state cooperation

At the federal level there are political sensitivities about government efforts to provide direct assistance to industry, there are many fewer inhibitions at state level. The states are estimated to be spending about $1 Billion in a variety of technology stimulation and industrial extension efforts. They compete with each other for investment creating quality new jobs, both from other states and from other countries.

It appears that a path that can be both politically acceptable and functionally effective for addressing the need to upgrade the technological performance of small to medium size business is for the federal government to work with and through the states, or regional associations of states.
If this does become the best strategy, the formulation of science and technology policy at the federal level will have to invite much more participation from states that it does today. This may require additional institutional innovations.

Defense Department and the industrial technology base

The role of the defense department, and alternatively the possibility of an expanded role for Commerce and the non-military technology agencies (DOE and NASA, particularly), is the other big question. This is a major subject of policy study at the Kennedy School, and I have testified on this point to other Senate Committees. Let me say here only that the past contributions of defense to commercial innovations is poorly understood and in some cases exaggerated.

Yet the defense department has more experience in and more resources for investment of new technology creation by firms than other agencies - certainly more than commerce. There is little doubt that Defense can make a greater contribution to the strength of the commercial sector, buy relying more on commercial products, by encouraging commercial firms with defense business units to take commercial advantage of government funded technology, and by a number of other changes.

However, one must recognize that the innovation process in the defense industry is in even more difficulty than that of commercial firms in international competition. The nature of the defense market is so different from commercial markets that it is far from clear that defense industry practises have anything to teach commercial firms about competing in civil markets. Nor is it clear that an agency like DARPA, which has a generally good reputation as a manager of exploratory technology development, would be able to operate in the same way or with the same success if it were located in Commerce.

Working out this issue - the synergy between defense and civil technology processes - will be a major issue for the executive and the congress.

Human Resources: K-12

The critical need is for a literate, competent workforce, which must reflect the demography of the nation - relying heavily on well educated minorities and women. A national commitment to radical change in the way our public school system is managed, enhancing the responsibilities, capabilities, and accountability of teachers, is the key.

The federal government must move beyond its largely passive role. My suggestion is that science and math education be taken as the starting point for supporting the reform efforts of the states. The NSF has access to the talent, understands the need for innovative improvements, and can drive the experimentation to find out with the states what strategies are effective. But NSF cannot be expected to reach enough schools to effect change nationally. That requires the Department of Education. The challenge for the President is, how can the Department of Education be induced to take an active role in school reform by cooperating with the NSF? Other agencies can also make a contribution. Admiral Watkins has pledged DOE's commitment to science education and is calling a high level conference next week to lay a plan.

Human Resources: engineering skills for manufacturing

The U.S. competitiveness problem is not, at heart, an R&D problem. The central issues are product appeal, cost and quality. These depend on design, process development, manufacturing systems engineering and quality management, all carried out in an innovation system that features very fast iteration to adapt to new news from the market or from science.

The mission is that of the factory, not the laboratory. But the skills are increasingly those Americans find only in the laboratory. We must address two issues at once:

(1) It is industry's job to remake their factories into places where high-technology can flourish, with factory managers who can attract high-skilled engineers and even scientists. This change is underway in many industries, but it requires huge cultural changes that are agonizingly slow to accomplish.

(2) It is engineering education's job to bring to the factory the full power of modern technology: computers, processes, materials and to provide role models for students that will motivate many of the bright ones to take up careers in production.

Where can engineering education hope to get financial help for this major change? Today they get increasing amounts of support from industry, but the process is to scattered, too small and too slow. But at NSF, the tradition is to bring about curriculum change through research funding. And since engineering receives less than a fifth of the research budget (although it is the fastest growth area), the leverage here is quite week.

I believe a frontal attack on the technical quality of our production base - primarily by voluntary association of industry and engineering education - but encouraged and supported by the federal government is urgently needed.

It is important to note, by way of justification, that the federal government is in part a cause of this split between industrial production technology and academic engineering education. This follows from the dominance of Defense, Energy and Space support for academic engineering. With rare exceptions, these agencies are not interested in technologies for low cost, mass production. They encourage engineers to find sophisticated technical solutions to problems with little regard to manufacturing or cost.

Information Infrastructure

Starting with the initiative so Hubert Humphrey in 1960, the U.S. built a quite sophisticated understanding of the importance of the science and technology information system -how to enhance the quality of technical results, avoid duplication, prepare the information for users and provide access to it. During the Nixon administration the federal focus on these issues started to crumble. Most of it has now been dismantled at a time when other nations, who learned the lesson from us, have now made major investments in their S&T

information infrastructure.

Following the Weinberg report of the President's Science Advisory Committee in Jan. 1963, the executive branch built a very sophisticated capability in technical information policy. The COSATI coordinated federal agency policy from OSTP. With American leadership the OECD played an important role internationally. The National Bureau of Standards undertook the National Standard Reference Data system. These were all path-making innovations, much copied by other countries.

But in 1973, when COSATI was transferred to NSF and died, this emphasis on getting good information in the hands of users gradually collapsed. Our de facto science policy is to create knowledge, and make it available to the world. But government does very little to make sure that Americans are helped to find it and use it.

To support the provision of information services to support technical productivity, there is a serious need for a national computer network of the sort studied by FCCST and addressed in this committee's legislative work. This is not the place to go into the policy issues, but there are many to be resolved. The advantages of the proposed capability could be very great however, if the network proves to be an effective support for the provision of information services and encourages them to be provided by firms as well as research institutions.

Federal Research Strategy: S&T Taxonomy

Another key issue is the need to define the kinds of science and technology support that is most needed from the federal government and to determine what agencies should be responsible for it.

An evaluation of the spectrum of technical efforts that make up the innovation process will show consensus on two points. Every one agrees the federal government must support the long range basic research. And every one agrees the government should not support the development of commercial products.

But we do not even have an agreed language to describe the kind of research that is of much more direct value to industry, while still appropriate for public investment.

I have in mind fundamental investigations into very practical questions - but still of great scientific and engineering importance: the characterization of new materials, research in opto-electronics, micromechanical engineering, new architectures for computers, bioengineering techniques for making useful enzymes, new algorithms for computer aided design and production, better ways to design and build computer software, unraveling the mysteries of catalysis, new kinds of scientific instruments or process tools.

These are the kinds of useful science and engineering research that are the daily bread and butter of academic engineering laboratories, and they are of great interest to scientists in universities, government laboratories and industry research laboratories as well. They receive heavy attention in Japan and Germany. But they are not the very most fashionable areas of science. They will not be as strong candidates as molecular biology, cosmology, or high energy physics when measured for their intrinsic intellectual potential.

We do not even have words that we can all use to describe this kind of science. Europeans would call it "pre-proprietary" or "strategic" research. American agencies sometimes call it "generic" research or "basic technology". The Pentagon calls it "exploratory development". Only the Japanese do not find this a problem. They call it "basic research".

The GAO has pointed out that the R&D taxonomy used by NSF and adopted by all the other civilian agencies has only the categories "basic" research, "applied" research, and "development"; while the Defense Department uses quite a different system. Until categories better related to the purpose of the investment are adopted it will be very difficult to build a rational budget process for making tradeoffs in the federal S&T budget.

The National Science Foundation has undertaken a study of the feasibility of changing the "taxonomy" of science and taxonomy to define categories of work by the determination of who are the intended beneficiaries of the work. This would be a great improvement over the old definitions, which were based on the attitudes of the research performers. And as a result of a Senate committee request the National Research Council is undertaking a review of the categories used in Defense budgets. These two projects, if brought together to produce a rational system for budgeting science and technology activities in the government, could provide the vehicle for clarifying what kinds of S&T programs would best serve the nation under the new circumstances. I strongly commend the Senate's attention to this issue, and suggest you follow it closely.

Federal Agency Missions and Organizations

In addition to the question of the role of the Defense Department in support of the industrial technology base, consideration will need to be given to how other agencies -especially DOE, NASA and NIH - can best contribute to the strengthening of that base. Should the Commerce Department be expected to acquire the capability to manage technology development as Senator Glenn and others have suggested? Or might some combination of DOE and perhaps NASA, be given new functions and relationships? Should NIH be expected to pursue its health mission with an eye on the health of the emerging biotechnology industry?

I suspect that over the next decade ways will be found to leverage the great capabilities of these three agencies more effectively in the interest of a strong economy. It is this context that might provide the best hope for assigning meaningful and challenging missions to the national laboratories, the largest of which belong to these three agencies.

Sustaining the health of the Science and Technology Enterprise.

Much has already been said about the serious need for rebuilding the facilities and equipment of the university research community and finding adequate funding for the students who are voting with their feet not to pursue careers in science and engineering. Dependency on foreign students to fill the faculty positions and the industrial research jobs is fraught with risk, as many of the countries who have sent such students are rapidly increasing their capacity to attract them home.

But in addition to these financial issues, there are some new ones that could be straws in the wind of serious problems ahead for American science.

"Earmarking"

The first is the growing politicization of Congressional appropriations for science - a natural consequence of the tight budgets and too long postponed facilities needs - but if not managed very carefully can destroy the competitive basis for resource allocation that protects the public purse and keeps the technical community struggling for excellence. The most sensitive issue is "earmarking".

The scientific community must understand that the support of science depends on the ability of elected officials to justify to their constituents these large investments, particularly when they compete for needed social services. The need to provide some geographical balance while preserving quality must be recognized.

The political community must understand the delicacy of the balance among competing institutions for science funding, especially in times when money is tight. If "earmarking" gets out of hand, and it has been growing apace in the last three years, it could destroy the comity on which the whole system of quality competition is based.

Standards of conduct and integrity in science.

The scientific community must address the growing public concern about allegations of scientific misconduct, particularly when public funds are involved. This has always been an issue the scientific community has been concerned about and must manage. It is appropriate for the funding agencies to care about the integrity of science and the possible abuse of federal support. But the way in which the problem is addressed could make the difference between new strength for science and a smothering blanket of bureaucratic process that eliminates the science along with the abuse.

Managing Science and Technology Policy and Making Choices

The President's decision to make Dr. Bromley his Assistant for Science and Technology, funding for the Office of Science and Technology Policy, along with relationships being forged between Dr. Bromley and the Dr. Sununu bode well for strengthening the management of S&T policy.

It is absolutely critical that the senior positions are staffed and confirmed swiftly. It is quite clear that heavy responsibilities will fall on the four senior officials in Bromley's office. The President will need to support their efforts to get the attention and cooperation of the agencies. It is incumbent on Dr. Bromley to build strong bridges to the leaders of industry.

Conclusion

It is bad enough that our private industry has become non-competitive in one area after another - consumer electronics, numerically controlled machine tools, large parts of microelectronics, fine ceramics, low end office machines, many areas of manufacturing equipment. Our public sector is becoming non-competitive too. We have allowed the $ 300 B education industry to fall into disrepair even though it must provide the basis for the industries in which we can hope to have a comparative advantage in the information age.

We surely do not resent the progress made by others. But when I go to Japan I hear good friends of America unable to understand why the United States, which they so admired and worked so hard to emulate, seems adrift, unable to foster, protect and exploit the talent for science, technology and entrepreneurship for which Americans are so justifiably famous. We Americans save too little, consume too much, and are living on borrowed foreign money and the sale of our capital assets: our land and our industry.

Our competitors are losing their respect for us, and as an American I find that very hard to take.

We need the vision and sense of purpose that Harry Truman expressed over 40 years ago, when he announced his intention to double the total public and private investment in science, to establish the National Science Foundation, to expand scholarships and research facilities in the universities and better finance and coordinate the work of federal research agencies:

"If we are to maintain the leadership in science that is essential to national strength," he said, "we must vigorously press ahead in research. There is one simple axiom on which this thought is based. The secrets of nature are not our monopoly. Any nation that is willing and able to make the effort can learn the secrets that we have learned."

"Now and in the years ahead," he went on to say, "we need more than anything else the honest and uncompromising common-sense of science. Science means a method of thought. That method is characterized by open-mindedness, honest, perseverance, and above all, by an unflinching passion for knowledge and truth. When more of the peoples of the world have learned the ways of thought of the scientist, we shall have better reason to expect lasting peace and a fuller life for all." [1]

(1) Truman, President Harry, address before the American Association for the Advancement of Science, Monday September 13, 1948, unpublished.

Senator **Gore**. Thank you for getting us off to such a good start. We will hold questions until all panel members complete their statements.

Our second witness is Dr. Donald Langenberg, President-Elect of the American Association for the Advancement of Science; also Chancellor of the University of Illinois at Chicago and thank you very much, Doctor. Please proceed.

STATEMENT OF DONALD N. LANGENBERG, PRESIDENT-ELECT, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE AND CHANCELLOR, UNIVERSITY OF ILLINOIS AT CHICAGO

Dr. **Langenberg**. Thank you, Mr. Chairman.

Let me use a few moments to make some assertions which I would be happy to defend in later questioning.

First, some comments on strengths and weaknesses of the current federal science and technology policy. I would like to distinguish between science policy and technology policy.

I think we have done a considerably better job on science policy than we have on technology policy. Part of that policy, as Dr. Branscomb has just observed has led through the "privatization of scientific research" to a longstanding partnership now running back four or five decades between the federal government and the universities, wherein most of the fundamental research of the nation is carried out.

I will make a couple of remarks about the health of that system later, but by and large it is in good condition. It is functioning rather well, I think, and it seems to me that that partnership must remain a fundamental tenet of our science policy.

Dr. Branscomb has also alluded, however, to a growing problem in priority setting. As some science gets bigger and as our national resources get more constrained, we have come to a time when there needs to be more discipline, more orderliness—not neatness, perhaps—in the way we set priorities within science.

There has been a considerable debate on that here in Washington. In a report from the National Academy of Sciences, the outlines of exactly how we would go about that in a coherent way remain somewhat unclear, but it seems fairly clear that the Office of Science and Technology Policy is the most likely candidate within the federal government to take the lead in working in this problem area.

A major strength of the United States does arise, I believe, from the diversity of support and in the conduct of science, scientific research and technological research. It is divided now roughly equally between the public and private sectors.

One facet of this enterprise that I think is not being fully appreciated is the important role that the states are now beginning to take in the promotion and the encouragement of scientific research and of technological development at the state level.

I think it is clear that that is becoming much more important than it used to be. The partnership used to be between the federal government and the universities on the scientific research side.

More and more of the states are playing an important role in what might be called now a trio of major players.

We do not know very much about what the states are doing. The National Science Foundation used to support financially and encourage relationships between scientific researchers and their institutions and states, and it used to track what was going on. It ceased to do that to any great extent some years ago, and I think we are now faced with a lot of uncertainty about just what is going on.

What is clear is there is a lot going on. The complexity and number of large problems seem to be growing. Global environmental change in the large is an outstanding example.

It is clear that we have got to make some significant changes in our structures for supporting and conducting research and for applying it to the solution of those problems.

While this is going on, there are an increasing number of indicators that the United States is, relatively speaking, losing position in some areas, in some fields and sometimes not relatively but absolutely losing position.

If one identifies the Office of Science and Technology Policy in the executive office of the President as the locus for federal leadership in the area of strategic planning and the area of priority setting, then it seems clear that some attention there is needed.

A major weakness in our policy system in recent years has been that that office does not appear to have performed in accordance with the expectations that were expressed in the National Science and Technology Policy Act of 1976.

There are encouraging signs, however, that that may be changing recently. As one looks to the general health of our science base in our research universities, again, I would say that in general that seems to be quite good.

I think as a cautionary note we need to be careful always to watch the balance between goal-oriented science and technology and the development of the science and technology base and not to invest disproportionately in goal-oriented or mission-oriented science and technology.

There are some problems in the system. It is clear, I think, that the U.S. academic research facility system has deteriorated and that, there is a major need to repair, renovate and modernize existing facilities as well as to expand and build additional ones.

In many ways it could be said that we are operating on a capital base that was constructed in the great expansion days of our universities in the fifties and sixties.

The deteriorating nature of that, plus the fact that scientific research is getting ever more complex and requires ever more sophisticated facilities and instrumentation means that here there is a problem. That problem must be addressed by the universities themselves, by the states, but the federal government surely has some role in that.

I would note that the United States R&D investment strategy over many past decades contrasts significantly with strategies that are being followed by some of our principal economic competitors; in particular, sustaining substantial R&D investment in a stable way.

And it seems to me that one area that requires more attention than it has been given is the question of DOD's contribution to the R&D enterprise of the nation and the part of that which relates to the maintenance of DOD's and, therefore, the nation's science and technology base.

As we all know, funding for R&D in the Department of Defense has increased markedly in recent years, but I think there is real reason to be concerned about the degree to which the Defense Department has been maintaining its own and the Nation's science and technology base within that.

One of the major issues in the field of science and technology is clearly the matter of science and engineering education both for those who will become the scientists and engineers of the future and for the general populace which is being asked increasingly to make decisions concerning issues that have major scientific and technological elements.

Here again, I think far too little attention has been given to approaching this set of problems in a strategic manner and in a coherent, linked manner, looking at all aspects of the problem.

Our education system in this country is a remarkably decentralized system. That causes us to seek solutions to its problems in a remarkably decentralized and parochial manner. Yet, given the concerns for which there are ample reasons demonstrated in something more than 300 reports in recent years, some kind of national coherent and strategic vision for education in general, and for education for scientists and technologists in particular, needs to be created.

We need to be concerned with the quality and training of all of our future work force, not just the scientists but those who will fuel our economy in general.

We have serious pipeline problems in our supply of scientists and engineers. We have major demographic trends that are strongly influencing the sources of our scientists and engineers and our work force in general. I will mention only one terribly important one, and that is that the proportion of minorities is increasing in the pool of our students, and with minorities and with women we have done an exceedingly poor job of attracting them into scientific and technological careers.

Richard Feynman once defined physics as something that physicists do late at night. It would be equally accurate to define physics as something done by white males. If we are going to maintain our ability to function as a scientific and technologically based Nation, that has to change.

Solving these problems will take personal and institutional commitments by all of us, but in this position Mr. Bush, mentioning specifically the educational summit that is currently in progress, has a major role to play in creating that strategic vision of our scientific and technological enterprise and the people that we must have to maintain and develop it further.

Thank you.

[The statement and questions and answers follow:]

Statement by

DONALD N. LANGENBERG

President-Elect

American Association for the Advancement of Science

Mr. Chairman and Members of the Subcommittee:

Thank you for your invitation to testify as part of your hearings on national science and technology policy.

I am Donald Langenberg, Chancellor, the University of Illinois at Chicago. However, today I am appearing as President-Elect of the American Association for the Advancement of Science. The AAAS is an organization of 133,000 scientists and engineers and has 295 affiliates representing over five million members in various scientific, engineering and professional societies. We publish the journal *Science* and a variety of science and technology policy documents.

A good example of the latter which is related to the topics of this oversight hearing is *R&D in the 1980s: A Special Report*. A copy is enclosed with my full written statement and you may wish to consider its utility as an appendix to your hearing record.

In response to your invitation letter, I plan to discuss briefly -- and in *highlight* fashion -- the following topics:

- The strengths and weaknesses of current federal science and technology policy
- The health of America's science base and research universities
- Problems and opportunities in the field of science and engineering education

I stress my *highlight treatment* of the requested topics; each is extraordinarily important and central to larger U.S. political and economic objectives -- domestically and internationally. Each could consume days and weeks of congressional hearings and, indeed, has in the recent past. Moreover, hundreds of reports and studies have been done on these same topics by dozens of organizations.

As I thought about what small value-added contribution I might make to your hearing -- since you have been inundated with many of these studies and reports just mentioned -- it seemed that some type of brief synthesis and summary of key points might be most useful to you. The downside of this approach is, of course, that the discussion of any single issue or point will necessarily be rather sketchy.

Finally, before turning to substance there is one final introductory comment: although "national science and technology policy" is often used as one term I will make some distinctions between "science policy" and "technology policy." They are related but sufficiently different as to call for separate analysis.

PART I: Strengths and Weaknesses of Current Federal Science and Technology Policy

Point 1: Science Policy -- A Major Strength. Nothing I have studied or encountered as a university researcher and chancellor or federal executive (Deputy Director of the National Science Foundation) has led me to call for any major policy change in the U.S. pluralistic system of support and conduct of science.

By this, I do not mean that no changes have taken place over time or that none will take place in the future; quite the contrary, within an overall policy framework the system has been and will remain very dynamic in responding to changing circumstances and requirements.

Rather, I mean that overall, the decades-long science partnership between the federal government and the universities has been tremendously successful and that this system must remain a basic tenet of U.S. science policy. It serves as a fundamental source of the major strengths of U.S. science in the way it is performed by individual researchers and research groups within an overall competitive framework of federal support and general priority setting. The latter item, however, takes me to a weakness.

Point 2: Science Policy -- A Weakness: In its report on the FY 1989 Budget Resolution, the Senate Budget Committee addressed one weakness of current science policy: growing problems in priority setting as requirements for science -- especially "big science" -- rise and resources become more scarce. The Committee called for a National Academy of Sciences study of the problems of setting budget priorities for science.

As my colleague, Robert Rosenzweig, Association of American Universities President, has testified before Congress: "A greater degree of order needs to be brought to the process -- not neatness or tidiness, which are unreasonable expectations, but a bit more order and discipline." Although the Academy's report was not a full answer to the problem posed to it by the Congress, it does represent a sizeable step in the right direction of "more order."

However, continuing work in this area will be necessary and, as I will develop shortly, the Office of Science and Technology Policy is the most likely candidate to take the lead. The Congress and the scientific and engineering communities will also have to play important roles in this evolving process.

Point 3: Science and Technology Policy: A Strength: A major strength of the U.S. arises from the great diversity of support and use of science and technology by the various sectors of our economy -- public and private. For example, Figure 1 illustrates the approximate division of support of science and technology -- or research and development, as it is measured -- between the public and private sectors. After some fluctuations over the past several decades, the ratio appears to have stabilized not far from a 50-50 division. (The comparable ratio in Japan is about 2-3 percent for the government and 97-98 percent for the private sector.) The positive interpretation of this ratio for the U.S. is that the support of national R&D is broadly based; a possible negative interpretation is -- as will be seen in later charts -- that some believe the large defense proportion of federal R&D may be one explainer of declining U.S. economic competition.

One facet of U.S. science and technology policy that is not well recognized and analyzed is the growing involvement of the states with the support and use of science and technology in dealing with a wide range of state and local problems -- ranging from economic growth to the environment. Indeed, the governors and their respective legislatures have become a literal fountainhead of innovations related to the use of scientific and technological advances. Regrettably, the National Science Foundation and other federal agencies greatly reduced supporting and tracking such activities in the early 1980s -- or even facilitating the exchange of experience and information. Nor have they sought opportunities to leverage state investment or harness state interest. However, there does seem to be some modest new interest arising in this area by the National Science Foundation.

Point 4: Science and Technology Policy -- A Major Concern A specific feature of the above-cited strengths and of current policy is that science and technology, in my view, are intrinsic elements of the missions of many governmental agencies and much of the private sector. There are few important national issues or problems which do not have some kind of scientific or technological component -- whether it be AIDS, economic competitiveness, air traffic control, or global environmental concerns.

However, it is clear that we are faced with growing complexity and rising numbers of large problems -- often with global dimensions. There also is an increasing number of indicators which suggest the U.S. is losing position relatively -- and sometimes absolutely -- in a variety of key scientific, technological and economic areas. This leads some observers to believe that we must do better in the ways we develop and implement various science and technology policies and programs.

One organizational solution which has been proposed from time to time is the establishment of a Department of Science and Technology. This issue has been debated off and on for more than a century and I will only say today that I do not think it is a good idea. There are far better ways to go, as I will discuss next.

Point 5: Science and Technology Policy: A Major Weakness While I remain convinced that our overall system of broadly-based, multiple private and public support and use of science and technology is the better approach for the U.S., I also agree with the view that there is room for improvement. More specifically -- and closely related to the basic purpose of your hearing -- the Office of Science and Technology Policy in the Executive Office of the President does not appear to have performed in accordance with expectations expressed in the National Science and Technology Policy Act of 1976. OSTP was intended, according to the legislative record as well as congressional-presidential negotiations, to perform in an integrative, coordinative manner for the nation and the federal government by adding an overall national dimension to individual governmental agencies and private sector efforts and programs.

Further, and I think extremely important, the Director of OSTP was to provide a strategic vision in advising the President on scientific and technological considerations in a wide variety of national and international concerns. This role was to include those issues where it is essential to meld S&T considerations with those having political, economic, and social dimensions.

Without belaboring this point further, since you discussed it at length with Dr. Bromley in his confirmation hearings, I would only add that I strongly support the expressed intention of the President to strengthen OSTP in a variety of ways -- including the designation of Dr. Bromley as Assistant to the President. Finally, this Committee is to be congratulated on its role in bringing about this strengthening of OSTP and advancing the purposes of the 1976 Act -- especially since your Committee was so instrumental in enacting that legislation.

Point 6: Technology Policy: A Major Weakness: Perhaps the word "weakness" is not the correct one to express what is more in the category of a "concern" about "technology policy." We in the U.S. have been much more clear and consistent in the areas of "science policy" than we have been in "technology policy." There is no time to develop the arguments fully today, but I would say that we must take a deeper look at technology policy. Indeed, I am heartened that one of the new Associate Directors of OSTP will deal with the general area of technology policy and industrial technology. I would hope that OSTP will deal with such issues as, for example:

1) Whether or not the U.S. would benefit from the establishment of an Advanced Civilian Technology Agency comparable to the Defense Department's DARPA (Defense Advanced Research Projects Agency) -- as some in Congress have proposed;
2) Whether or not tax policies need revision to make the expiring R&D tax credit permanent and more broadly applicable; and,
3) Whether or not we should expand more rapidly National Science Foundation,

Department of Commerce and Defense Department initiatives aimed at increasing the effectiveness of partnerships among industry, universities and government for transforming scientific and technological advances into economic progress and the solution of national and international problems.

4) How can we more effectively address the growing number of issues involving scientific and technological considerations as well as others -- and which have international dimensions. Such matters range all the way from global warming to cooperative arrangements on large-scale projects in "big science."

More generally, as we examine alternative policies for the future, it is time that we move away from the simplistic political nostrums of past debates. All too often these debates have been polarized in terms of extreme positions such as "major government investments are needed in key technologies" or "government can never pick winners, only the market can." The chains of ideology must be broken so that we may take more realistic views of how the world is changing and what is happening among our economic competitors. The basic point is, I think, that we must shape new strategies -- including science and technology policies.

More generally, these strategies and policies must be part of a larger set of national objectives aimed at reducing the budget deficit, reducing the trade deficit, encouraging capital investment in technological innovation, improving the quality of our workforce, and improving the quality of our educational system.

In no way do I claim that effective science and technology policies will be the panacea for solving all of our problems. However, I do argue that they will be of vital importance. The Nobel-winning work of Robert Solow at M.I.T. and others such as Ralph Landau and Michael Boskin of Harvard and Stanford unequivocally underscores the fundamental connection between achieving the objectives cited in the preceding paragraph and achieving long-term, sustained U.S. economic growth.

Point 7: A Major Conclusion: All of what I have said so far leads me to conclude that the basic structure of our science and technology system is reasonably sound -- but it does require some significant rethinking and remodelling. However, the nature of our political system presents some rather severe obstacles -- as you know better than I -- to the kind of strategic rethinking which seems necessary.

Along with the many strengths of our system, our dark side seems to be a disinclination and inability to approach major problems from a strategic point of view. Rather, we tend to solve specific problems -- often rather narrowly defined -- with specific programs having relatively little reference to larger objectives and settings. I tell you nothing new when I emphasize how the jurisdictional divisions within Congress encourage this latter approach.

However, I do urge -- as I have urged for the Executive Office of the President and the Office of Science and Technology Policy -- that Congress place increasing attention on how it can cope strategically with the growing number of large, complex cross-cutting issues. The stakes are too high to allow each Senator and Representative and Committee to push for "their" specific piece of legislation which embraces "their" solution to one segment of, say, the "economic competitiveness" problem or the "education" problem. Perhaps we could build on the more comprehensive approach used during the past 2-3 years in developing the Omnibus Trade Act of 1988.

PART II: The Health of America's Science Base and Research Universities

Point 1: An Overview: This is another formidable task to cover in a few pages. At the risk of leaving out important dimensions and features, I'll venture several summary observations which will be open to elaboration. In the previous section I expressed my feeling that -- in general -- U.S. science and technology policies are essentially sound. This now also applies in general to the state of health of American science and the research universities -- with exceptions which I will highlight.

In suggesting a possible future Committee inquiry in this area, I call to your attention a major, upcoming report of the National Science Foundation which should be available later this year. It is called "The State of Academic Science and Engineering," and is intended to be part of an on-going analysis and monitoring of the federal-university relationship in science.

As a preliminary reviewer, I have found it to be a valuable portrait of the growth and transformation of universities as the loci of fundamental scientific research, and as centers of science and engineering education. This federal-university partnership for science of more than four decades duration -- which is increasingly incorporating industry as an additional partner -- is generally robust and healthy.

It is amazingly dynamic and adaptable to changing times and circumstances -- whether it be to move into the space sciences (1960s) or into AIDS and biotechnology (1980s) or economic competitiveness (1990s) as new areas of research. Another important dimension of the research system is the transformation of the ways in which research itself is conducted over time. Dramatic changes are taking place under the impact of the revolution in information technology -- as this Committee well knows.

Point 2: Several Problems Areas: Two problems areas are addressed in the other two parts of my statement: one deals with the increasingly difficult task of setting priorities within science and between science and other national priorities; the other deals with emerging faculty and researcher shortages during the 1990s in a number of fields.

Not unrelated to these problems are the suggestions of the National Academy of Sciences in its 1989 report to the Congress that three major categories be established for evaluating science expenditures: (1) investments in the S&T base; (2) S&T activities that contribute significantly to economic, social and political goals; and (3) new S&T initiatives, including but not limited to those that are heavily capital-intensive.

My point is that the long-term health of American science will be a function of levels of investment in all of these categories. However, from my perspective as a university researcher and chancellor -- as well as my position in the AAAS -- it is imperative that investing in the second and third areas must not be at the expense of the S&T base. As I will demonstrate in at least one area -- defense -- there is some reason for concern.

Point 3: Academic Research Facilities Problems: You may well be weary of hearing about this issue -- especially in the context of numerous comments within and outside the Congress about "pork barrel science facilities" -- but it will not go away. Well-documented studies by the National Science Foundation and others show that U.S. academic research facilities have deteriorated and that there is a need to repair, renovate, and modernize existing facilities as well as to expand and build additional ones. (For the most recent data see Modernizing Academic Research Facilities: A Comprehensive Plan, NSF, June 1989.)

The Academic Research Facilities Modernization Act of 1988, signed into law in October 1988, was the result of a number of legislative initiatives to deal with an overwhelmingly apparent need. By way of reminder, the Act provides authority for the NSF to establish and carry out an Academic Research Facilities Modernization Program. A roughly $900 million program over five years was authorized -- but no money has been appropriated so far.

Point 4: R&D Support -- A Profile: There is no doubt that we are investing a lot of money in R&D. However, as will be seen, these amounts cannot be examined in isolation. While it is true that the large and growing size of the U.S. economy results in R&D expenditures larger than those of other countries and some of these countries combined. But when we look further at a number of international comparisons, there arises some cause for concern.

- As shown in Figure 2, the total annual investment in R&D has increased more than five-fold in real terms between 1953 and 1988. What is disturbing, however, is the long, nearly 15-year plateau of no real growth from the mid-1960s to the late 1970s. And there is no cause for jubilation as one ponders the potential implications of the growth curve beginning to flatten out in the latter half of the 1980s -- especially as the NSF has reported that industry R&D has been cut back recently. At the risk of oversimplifying a very complex matter, I offer a few of my own views about this data. The long period of no real growth in total R&D investment explains, in part:

(1) Lowered U.S. economic competitiveness as reflected in a number of measures, not the least of which are the massive trade deficits and the emerging strong positions of foreigners in U.S. patent awards; and

(2) Lower U.S. manufacturing productivity than in Japan and West Germany.

- The U.S. R&D investment strategy of those years contrasts sharply and negatively with the strategies followed by our principal economic competitors: substantial, sustained R&D investment. The data shown in Figures 3 and 4 -- comparative national ratios showing R&D as a percent of GNP with and without defense R&D -- underscore the major strategic differences between the U.S. and Britain compared with Japan and West Germany. Without the defense R&D, as shown in Figure 4, the latter two countries show an obvious relative advantage with respect to civilian R&D investment. The large and controversial policy question here revolves around the so-called "dual technology" concept. In short, does defense R&D have use for the civilian economy as well as for defense purposes?

- The data in Figures 5 and 6 show that federal support for basic research has been substantially increased in current dollars since the late 1970s -- which is certainly an important feature of the improved health of American science. Further, academic R&D -- as reported by the NSF -- has grown significantly since the mid-1970s, and world references to U.S. scientific work (citations) remains relatively strong at about one-third of the total (with only a very modest decline from the mid-1970s to the mid-1980s).

Point 5: Defense R&D -- A Brief Look: It is not my intention to examine the entire subject of defense R&D or the on-going debate about the balance between defense and civilian R&D. However, in the context of your concern about the health of America's science base, I will address the Department of Defense's "Technology Base" activities. As is noted in OTA's March 1988 report on "The Defense Technology Base," there are some definitional problems in discussing this topic. Strictly speaking, the Office of the Secretary of Defense has defined the "technology base programs" as consisting of Programs 6.1 (basic research) and 6.2 (exploratory development). However, another Defense

Department definition has defined science and technology programs as including "technology base programs" along with Program 6.3A (advanced technology development).

A major policy implication of these definitional treatments is that some include the Strategic Defense Initiative as part of the technology base programs while others claim this is not proper due to its strong developmental focus and its association with anti-ballistic missile warfare.

Figure 7 shows a comparison -- in constant 1982 dollars -- of DOD's total RDT&E program with the "technology base." The bottom part of the graph shows the "technology base" with and without the SDI. Without the SDI, the defense "technology base" is just about where it was twenty years ago. Figures 8 and 9 show vividly how the real amounts of DOD-supported basic research and applied research -- that is, the technology base -- has deteriorated over time. I think this long, downward trend in DOD's technology base is something we must be greatly concerned about in the context of the health of American science. It may even be appropriate to raise the question of defense carrying its "fair share" of the nation's investment in research -- as opposed to development.

PART III: Problems and Opportunities in the Field of Science and Engineering Education

Point 1: An Overview: Many in the scientific and engineering communities would say that the set of human resource problems related to education and workforce quality comprise the most serious science and technology policy issue we face today. It certainly is among a small set of the most serious.

For more than a decade we have been studying the various facets of this policy issue and well over 300 reports have emerged. We have identified most of the problems. Perhaps a better way of saying this is that we know the symptoms and have collected what amounts to an overwhelmingly dismal array of indicators. They point to extremely serious shortcomings and flaws related to education and the human resource base for science and engineering in this country.

In my brief commentary today I can only lightly touch on a representative number of these indicators, mention several exceptionally important reports, identify some key issues and suggest a broad set of objectives and strategies.

Point 2: A Major Conclusion: A positive result of all the studies and reports is that hardly anyone disagrees with the idea that we do have serious problems and almost everyone thinks we ought to do something about them. The negative result is that many dozens of solutions have been presented to solve some small or large piece of the "overall problem."

For example, we at the AAAS have been asked to testify before Congress and to comment on dozens of specific legislative proposals. And here I do not wish to sound negative or condescending, but the reality of congressional structure -- discussed earlier -- leads to few of these proposals having a sense of connectedness to larger, systemic approaches. Each is addressed to some limited piece of the overall set of problems. In summary, there has been much too little attention given to approaching this set of problems in education from an overall or systems point of view. It may well be unrealistic to call for such an approach given the enormous complexity, the many unrecognized interactions among the parts, and the highly decentralized nature of our political and educational "systems." Yet, I firmly believe that we must move in that direction if we are to achieve other than marginal results in the long run.

One positive step in this direction is the "Education Summit" being held this week by the President and the Governors. However, as laudable as this concept is, key players such as the Congress and education representatives are not involved. The Charlottesville gathering should be the beginning of shaping a set of national strategies; it should not end up as a single event having largely ceremonial overtones.

Point 3: One Approach to Sorting the Key Issues and a Limited Listing of Major Reports As a modest attempt to sort out the key issues, we have examined a large number of the reports. While not all would agree that the following listing is fully comprehensive or adequately captures essential points, I would say that here are most of the significant issues:

- Quality and training -- including scientific and technical literacy -- of the current and future workforce
- Quality and quantity of scientists and engineers required for our economic and educational systems -- increasingly referred to as "the pipeline" (See Figure 10 -- a representation of the "pipeline" from the OTA report noted below)
- Quality and quantity of science and mathematics teachers for the primary and secondary schools
- Demographic trends

Several representative major reports are listed in Appendix A.

Point 4: Key Objectives for Improvement: Within the larger system approach to understanding the problems and potential solutions, there are identifiable major objectives. Among these are:

- Readying more students to enter the workforce and science and engineering "pipeline"
- Recruiting new students to enlarge the "pipeline" flow
- Retaining students (reducing attrition and dropout rates)
- Attracting new teachers and improving their quality along with that of current teachers
- Improving the effectiveness of curricula at all levels

Point 5: A Brief Review of Some Indicators of Problems: While many of these items will, of course, not be new to you, they are offered to reinforce our views about the gravity of the problems and the need for action. For example:

- There has been a serious decline in the number of U.S. citizens receiving Ph.D.'s, particularly in the physical sciences, engineering and mathematical sciences. In 1987 only 42 percent of U.S.-granted Ph.D.'s in engineering were awarded to U.S. citizens.
- There has been a declining interest in science careers by U.S. freshmen in

American colleges and universities: in 1973, 11.5 percent of college freshmen reported plans to major in science; by 1988 that proportion had dropped to 5.8 percent of a smaller demographic cohort.

- We have been experiencing consistently low enrollments in high school physical sciences and advanced mathematics courses.
- Losses from the "S&E pipeline" occur at every level (the policy implication is that every level is a potential candidate for intervention -- with due attention to overall impact).
- By 1995 about 30 percent of the engineering faculty in U.S. universities will have retired and have to be replaced (an emerging trend is that many of these replacements will be from other countries).
- International comparisons -- which I'm sure you have seen -- show American youth lagging far behind their counterparts in other countries in mathematics and science achievement.
- In 1985, the National Science Board reported that relatively large numbers of teachers were not certified to teach in the fields to which they were assigned -- including science and mathematics. In this same area, a National Science Teachers Association survey found that only about two-thirds of science teachers in grades 7-9 met the Association's preparation standards; at the 10-12 level, the proportion fell to only 57 percent.
- Finally, women are a growing proportion of all college students; minorities are a growing proportion of all 18-24 year olds in this country. Yet, these groups traditionally participate in scientific and engineering careers at rates far below that which would be anticipated based on their proportion of the professional/technical workforce.

Point 6: A Summary View: The above litany of negative indicators could go on and on. The major positives which can be drawn from all of these reports and the nationwide debate underway are that we recognize the gravity of the problems and are beginning to articulate solutions. In the event the Committee so wishes, the AAAS is prepared to submit for your hearing record an extensive summary of improvement measures which could be taken.

However, in the long run, as I observed earlier, we must do a better job of "tying things together." I believe this "tying together" must entail prominent roles by the federal government, the states, the scientific and engineering communities and local school districts in new kinds of partnerships that include communities, families, and industry. I hope a deeper understanding of this need will emerge from the Charlottesville meeting, but you in the Congress must also join in this comprehensive debate.

As my fellow officer and Board Chairman of the AAAS, Walter E. Massey, has observed in a recent issue of Science, it will take personal and institutional commitments by all of us. And in this situation, President Bush has a marvelous opportunity to provide the personal leadership for us to generate a national, sustained commitment to the improvement of education at all levels, within the schools and the workplace as well. Thank you very much.

FIGURE 1

Federal & Non-Federal R & D Outlays

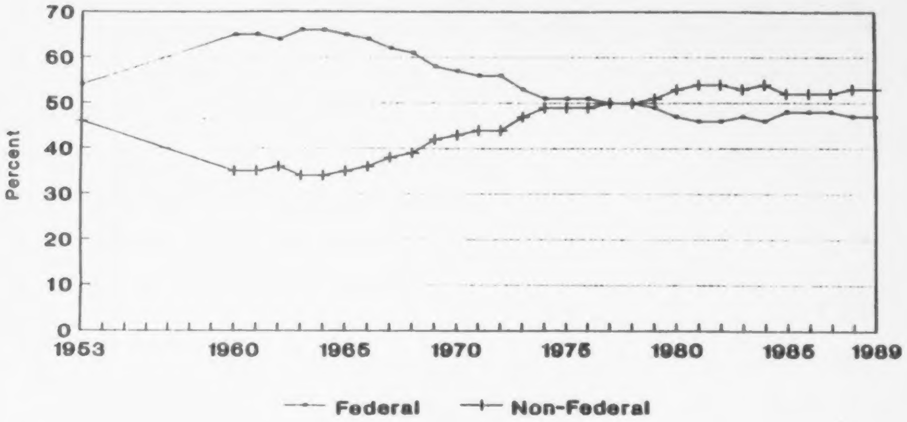
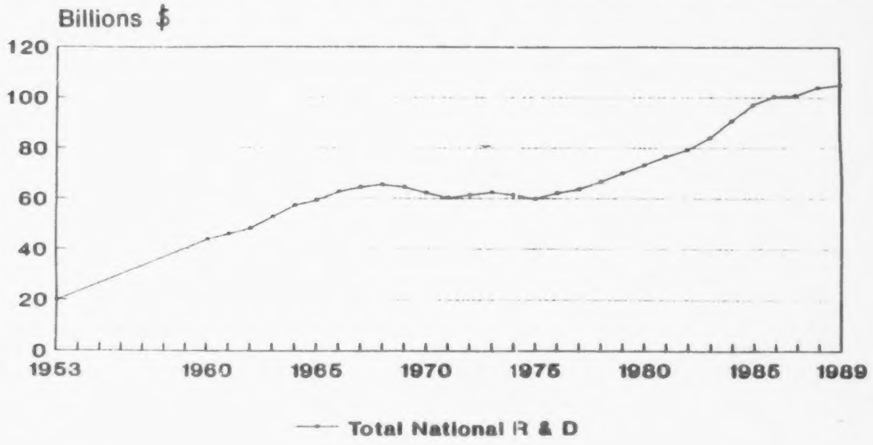


FIGURE 2

Total National R & D - Constant $ 1982



Source: N.S.F.

FIGURE 3 - National Expenditures for Performance of R & D as Percent of GNP by Country 1961-87

Year	France	West Germany	Japan	United Kingdom	United States
1961	1.4	NA	1.4	2.5	2.7
1962	1.5	1.4	1.5	NA	2.7
1963	1.6	1.4	1.4	NA	2.9
1964	1.8	1.6	1.5	2.3	2.9
1965	2.0	1.7	1.6	NA	2.9
1966	2.0	1.8	1.5	2.3	2.9
1967	2.1	2.0	1.6	2.3	2.9
1968	2.1	2.0	1.7	2.2	2.8
1969	1.9	1.8	1.7	2.3	2.7
1970	1.9	2.0	1.9	NA	2.6
1971	1.9	2.2	1.9	NA	2.4
1972	1.9	2.2	1.9	2.1	2.3
1973	1.8	2.1	2.0	NA	2.3
1974	1.8	2.1	2.0	NA	2.2
1975	1.8	2.2	2.0	2.1	2.2
1976	1.8	2.1	2.0	NA	2.2
1977	1.8	2.1	2.0	NA	2.1
1978	1.8	2.2	2.0	2.2	2.1
1979	1.8	2.4	2.1	NA	2.2
1980	1.8	2.4	2.2	NA	2.3
1981	2.0	2.5	2.3	2.4	2.4
1982	2.1	2.6	2.4	NA	2.5
1983	2.1	2.6	2.6	2.2	2.6
1984	2.2	2.6	2.6	NA	2.6
1985	2.3	2.8	2.8	2.3	2.7
1986	2.3	2.7	2.8	2.4	2.7
1987	2.3	2.7	2.8	NA	2.6

FIGURE 4 - Estimated Ratio of Civilian R & D Expenditures to GNP for Selected Countries 1967-87

Year	France	West Germany	Japan	United Kingdom	United States
1967	NA	NA	1.5	NA	1.9
1968	NA	1.8	1.9	NA	1.8
1969	NA	1.9	1.6	NA	1.8
1970	NA	2.0	1.8	NA	1.8
1971	1.5	2.0	1.9	NA	1.6
1972	1.5	2.1	1.9	1.5	1.6
1973	1.4	1.9	2.0	NA	1.6
1974	1.4	2.0	2.0	NA	1.6
1975	1.5	2.1	2.0	1.5	1.6
1976	1.4	2.0	2.0	NA	1.6
1977	1.4	2.0	2.0	NA	1.6
1978	1.4	2.1	2.0	1.6	1.6
1979	1.4	2.3	2.1	NA	1.7
1980	1.4	2.3	2.2	NA	1.8
1981	1.5	2.4	2.3	1.7	1.8
1982	1.6	2.5	2.3	1.7	1.8
1983	1.7	2.5	2.5	1.6	1.9
1984	1.8	2.5	2.6	NA	1.8
1985	NA	2.6	2.8	1.8	1.8
1986	1.9	2.6	2.8	1.8	1.8
1987	1.8	2.6	2.8	NA	1.7

Sources: N.S.F., O.E.C.D.

FIGURE 5 - Fiscal Years 1978-89
Budget Authority for Basic Research by Function

Function	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988 est	1989 est
Total	$3,665	$4,100	$4,716	$5,167	$5,385	$6,267	$7,072	$7,818	$8,191	$9,021	$9,330	$10,319
Health	1,266	1,370	1,703	1,931	1,933	2,473	2,811	3,203	3,324	3,836	4,133	4,253
General science	902	1,036	1,152	1,236	1,296	1,430	1,606	1,779	1,795	1,962	2,045	2,415
Space research and technology	412	440	482	443	436	501	646	698	737	843	840	1,062
National defense	330	365	332	610	605	708	843	836	900	900	907	924
Energy	157	172	200	230	260	329	365	428	436	311	360	371
Agriculture	197	222	246	281	295	326	353	406	390	397	417	450
Transportation	70	73	79	80	102	117	123	253	184	231	226	329
Natural resources and environment	207	131	136	131	129	156	182	286	264	286	217	200
Education, training, employment and social services	57	59	61	66	78	70	77	86	85	78	83	84
Commerce and housing credit	9	10	15	17	17	19	20	23	26	28	27	27
Veterans benefits and services	9	10	16	15	13	14	13	15	15	17	19	17
Administration of justice	10	10	9	5	4	6	3	4	5	8	9	6
General government	-	(a)	(a)	3	2	3	3	4	5	4	5	3
Community and regional development	0	0	0	5	7	6	5	6	6	4	4	3
International affairs	(a)	-	-	12	10	10	3	4	3	3	2	1
Income security	2	1	1	5	-	-	-	-	-	-	-	-

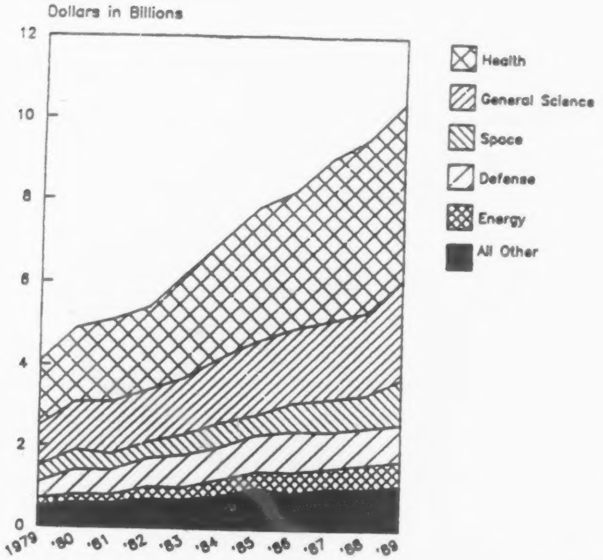
(a) Less than $500,000

Note: Data for 1978-87 are shown in actual budget authority. Data for 1988 and 1989 are estimates based on the FY 1989 budget.

SOURCE: National Science Foundation, SRS

(Dollars in Millions) FEDERAL BASIC RESEARCH

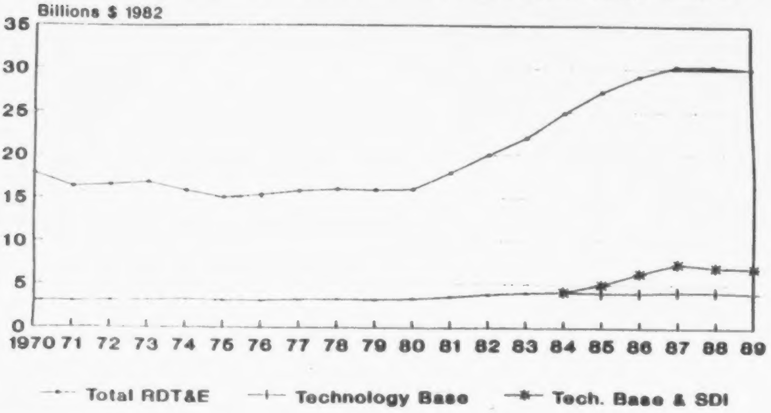
FIGURE 6
Federal Basic Research by Major Function



SOURCE: National Science Foundation, SRS

FIGURE 7

Comparison of RDT&E and Technology Base



Data provided by OSD (Billions 1982$)

FIGURE 8

Science and Technology Trend

IN CURRENT AND CONSTANT DOLLARS

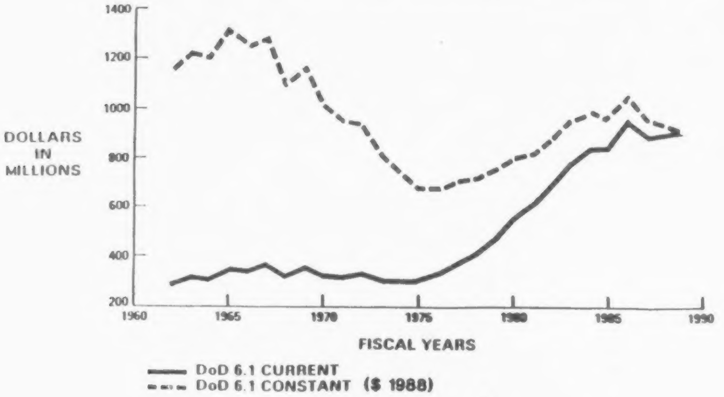
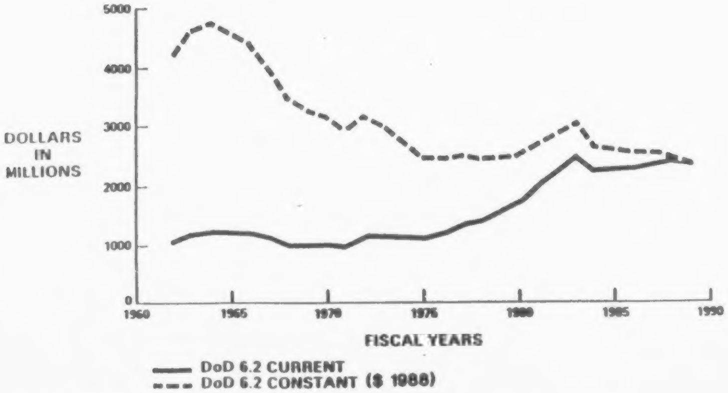


FIGURE 9

Science and Technology Trend

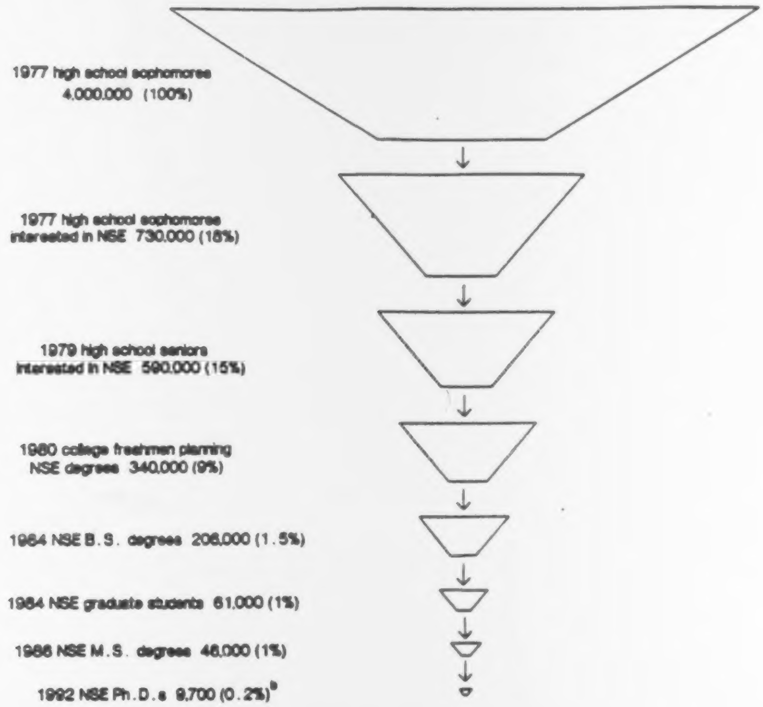
IN CURRENT AND CONSTANT DOLLARS



Source: DoD

FIGURE 10

Figure 1-4.—Natural Science/Engineering[a] Pipeline: Following a Class From High School Through Graduate School


1977 high school sophomores
4,000,000 (100%)
1977 high school sophomores interested in NSE 730,000 (18%)
1979 high school seniors interested in NSE 590,000 (15%)
1980 college freshmen planning NSE degrees 340,000 (9%)
1984 NSE B.S. degrees 206,000 (1.5%)
1984 NSE graduate students 61,000 (1%)
1986 NSE M.S. degrees 46,000 (1%)
1992 NSE Ph.D.s 9,700 (0.2%)[b]

[a] Natural science/engineering (NSE) includes physical, mathematical, and life sciences, and engineering, but not the social sciences.

[b] National Science Foundation estimate, based on the historical rate in NSE of 5 percent of B.S. graduates going on for Ph.D.s (using an 8-year average lag time from B.S. to Ph.D.). If market conditions increase demand for Ph.D.s, then this estimate may understate future production of NSE Ph.D.s. The number of NSE Ph.D.s in 1986 was about 12,000, or over 7 percent of NSE B.S. graduates in 1978 (Center for Education Statistics degree data). Assuming 7 percent of 1984 B.S. graduates rather than 5 percent go on for Ph.D.s would project 14,400 NSE Ph.D.s in 1992 rather than 9,700. Other methods of prediction (for instance, estimating Ph.D.s as a percent of the 30-year-old age cohort) show similar responsiveness to changing participation rates and assumptions. The Ph.D. population is very small and responds to changing conditions in academia and the job market, so that population-based estimates should be taken as rough indicators or warning signals rather than as solid predictions.

NOTE: These National Science Foundation estimates indicate the general pattern of the NSE pipeline, but are not actual numbers of students in the pipeline. (For instance, actual natural science/engineering B.S. production was 208,000 in 1984, Center for Education Statistics data.) The estimates are based on data from the U.S. Department of Education-sponsored National Longitudinal Study of 1972 Seniors (for the high school senior through graduate school transitions) and High School and Beyond Study of 1980 Seniors (for the high school sophomore to high school senior transition). Since the National Longitudinal Study was conducted, student interest in NSE majors has risen, but it is not yet clear whether trends in student interest with time will follow the pattern of 1972 high school seniors revealed by the National Longitudinal Study.

SOURCE: National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2, April 1987, p. 3; and personal communication with National Science Foundation staff.

Dr. Langenberg: We face serious shortages of faculty and researchers in our educational institutions at all levels -- at our most prestigious research institutions, at all other colleges and universities, in our high schools. Keeping the best scientists in educational settings is important not only for the benefits of their research, but because they train the next generation of scientists. And science and engineering faculty at the next level of institutions train industry engineers and technological workers. How do we keep and attract scientists to academia? Is it primarily a function of salary and more lucrative opprtunities in the private sector? Would scientists stay in academia if they had more support and better facilities?

American
Association
for the Advancement of
Science

1333 H STREET, N.W., WASHINGTON, D.C. 20005 (202) 326-6400
CABLE ADDRESS ADVANCESCI

DONALD N. LANGENBERG
President-Elect

UNIVERSITY OF ILLINOIS AT CHICAGO
601 S. MORGAN STREET
2833 UNIVERSITY HALL
CHICAGO, ILLINOIS 60607
(312) 413-3350

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October 11, 1989

The Honorable Ernest F. Hollings, Chairman
Committee on Commerce, Science, and Transportation
United States Senate
Washington, DC 20510-6125

Dear Senator Hollings:

Thank you for your kind letter of October 3. It was a pleasure to testify on behalf of the American Association for the Advancement of Science at Senator Gore's September 28 hearing on national science and technology policy. Following is my written response to Senator John Kerry's questions to me (copy attached):

> I agree wholeheartedly with your statement on the importance of attracting scientists and engineers to academic positions and keeping them there. Shortages of faculty seem likely to become one of the most critical problems facing our colleges and universities during the next decade.
>
> In most fields of science and engineering, a newly-minted Ph.D. frequently has a choice among career opportunities in academe, in industry, in government, and in non-profit private research institutions. Salary is certainly one of the factors which influence the Ph.D.'s choice among these alternatives. It is by no means the only factor, however, and often it is not the most important one. To a fledgling researcher, a situation in which he/she can freely and independently pursue his/her own research directions among first-rate colleagues and mentors is extremely attractive. For many, the opportunity to teach and to work with students is also a strong attraction. These characteristics of the academic environment often justify acceptance of a salary substantially lower than might be offered by an industrial laboratory, for example. Of course, the

academic salary cannot be too low relative to the industrial salary. In my experience, the acceptable balance point in the tradeoff between salary and the attractions of academe seems to occur when the academic salary (from all sources) is roughly three-quarters of the industrial salary.

An additional and extremely important qualification must be noted. The free and independent pursuit of research in an academic setting is possible **only** where there is a reasonable likelihood of adequate and fairly stable funding for the research, and adequate physical facilities and support services. If these are not available, no amount of salary will attract or keep a good researcher in an academic institution.

In my opinion, therefore, if the Federal government wishes to do its part to ensure the continuing vitality of our Nation's research universities, which perform the majority of our fundamental research and at the graduate level train **all** of our scientists and engineers (except for those we import from abroad), including particularly our future faculty members, it must maintain and strengthen its support for our academic research enterprise. This means both direct support for research and support for the research infrastructure which makes it possible, e.g., physical facilities, instrumentation, and support services such as libraries, computing facilities, and computer networks.

It would also be helpful if the Federal government would refrain from doing something. There have been several recent instances in which legislated salary reimbursement caps have appeared in authorization or appropriation bills for major Federal R&D funding agencies. Salary levels for the best academic researchers are every bit as subject to market forces as the salaries of baseball players, rock singers, business executives, and grocery clerks. To link salary reimbursement from Federal sources for academic researchers with a Federal compensation system constrained at the top by political rather than market forces is counterproductive at best. This problem has not yet reached serious proportions, but the trend is a matter of concern. (I am moved to note, incidentally, that the situation with respect to the Federal government's ability to provide competitive compensation levels for its own scientists and engineers appears to be evolving inexorably from crisis to catastrophe. It is difficult to imagine how a Federal government devoid of technical competence is going to lead a nation which has hitched its wagon to the star of science and technology.)

I hope Senator Kerry will find these comments responsive to his questions.

Sincerely yours,

Donald N. Langenberg

Donald N. Langenberg
President-Elect

Senator GORE. Thank you very much.

Our third witness on this panel is Dr. Robert Costello, a Senior Fellow with the Hudson Institute.

Dr. Costello, welcome and please proceed.

STATEMENT OF DR. ROBERT COSTELLO, SENIOR FELLOW, HUDSON INSTITUTE

Dr. COSTELLO. I am not from Tennessee, but we do have something in common, our interest in science and technology. I was going to mention to Senator Kerry that I came down here from Nantucket Island, and until the middle of June Senator Robb was my Senator. So we do have some relationship to the rest of the group here as well.

It is a pleasure for me to be here because I was the Under Secretary of Defense for Acquisition, and I have some perspective gained from my work there; but also as a member of the Hudson Institute where we are putting together a cross-section of industry, academia and government to generate an agenda for American leadership in manufacturing and technology.

If you will bear with me, Mr. Chairman, I would like to submit the outline for that work as part of the record.

Senator GORE. Without objection, we will include your statement.

Dr. COSTELLO. I think it is important that we get a broad spectrum not only from one industry but from industry in general together wtih academia and various segments of government that work with us.

The State activities have been mentioned, and I think the State governments have an active role to play. They basically have put together for themselves an industrial strategy.

I want to make a statement that is a contradiction perhaps to some of the people in the administration. We have an industrial strategy. We have always had one. Our strategy is not to have a strategy. It is impossible not to have one. What we have invited perhaps by not having a coherent long term strategy is a little bit of chaos.

Obviously, technology is key for our leadership in defense as well as the area of industrial competitiveness. It should be noted that depending on whose numbers you use, the Defense Department pays for up to 40 percent of the R&D in the country and, therefore, Defense has a very significant role to play. It has had a significant role to play, but that role is rapidly changing.

Any effort in technological leadership has to be in partnership with what Defense is doing. Years ago they were the leader, the director of technological leadership change. Today they no longer can afford that unique position.

I have been involved in industrial and military R&D since the 1950s, and we have been looking for that magic of spinoff so we could point to it and say "see how successful Defense has been." There have been not many activities in which we could readily point to Defense. I agree that implementation of these technologies into the commercial sector has not been particularly productive.

While I was in the Department of Defense, we were able to take some positive actions, and the spinoff could be accelerated if we continue to support activities such as Sematech, the consortium of semiconductor corporations involved in an activity for process and manufacturing technology; the National Center for Manufacturing Science; the structuring of the Defense Manufacturing Board as an independent body; and even the reorganization of DARPA. These are the most obvious changes we have put in place to enhance this spinoff and the development of a perspective that focused on implementation of new ideas, new concepts in technology by industry.

These efforts now allow Defense to support R&D in dual use technologies, which I think will become extremely important; that is, they have use for both commercial and defense needs, meet both the commercial and defense needs to establish and maintain our technological leadership.

If Defense does not support these dual use technologies, I think they are going to be in a position where they cannot afford the infrastructure for leadership in the unique technologies that they have been pursuing.

When they try to support the unique technologies, they end up with B2s that cost over $500 million apiece. That is an infrastructure that nobody can afford.

They have programs such as JSTARS which are extremely important to us, but which are only partially funded. JSARS, for example, is always under attack. It really depends on an infrastructure of data collection, processing, and dissemination that they have not been adequately supported. So they have to have dual use capabilities available to them to provide the broad manufacturing and technological infrastructure needed for continued leadership.

If we look at the new role of the Defense Department and if we take advantage of some of the changes in the strategic efforts that we are facing today, there must be a major effort on remote sensing for gathering information, processing that information rapidly and then disseminating it to the active forces so they can use it directly. The most advanced fighter capabilities we have have nightly patrols. The maps are older than the airplanes by far, and they are older than the pilots by far. Some of the maps date back to 1948, which is not good nor does it reflect the potential of even current technology in this information age.

We need to put together a very comprehensive integrated digitized fiber optic network for communications. That technology cannot be supported by Defense alone. It is the technology that we have looked at with the Department of Commerce for HDTV, a comprehensive system for the United States, a fiber optic, digital, interactive communication network. Defense needs it because they need to be able to gather and disseminate for their own use a wide variety of information.

They cannot do it by themselves. They need to have broad commercial applications of these same technologies, to establish a high quality, high technology infrastructure as a base for their use and leadership.

Dual use technologies are key to them. It is important that we use the resources of the Defense Department, the funding in particular, to support those activities that enhance the science as well as the implementation both for commercial and defense uses.

The leadership is a must if we are to maintain the security of the Nation and our leadership and our competitive posture in the industrial world in this information age. Dual use, dual funding, dual benefits are the only way to go. I think this is a very, very different role for the Defense Department and government to take.

I will look forward to questions.

[The statement follows:]

STATEMENT OF ROBERT COSTELLO, SENIOR FELLOW, HUDSON INSTITUTE, INDIANAPOLIS, IN

MR. CHAIRMAN AND MEMBERS OF THE COMMITTEE:

It is a pleasure for me to present this testimony before the Senate Committee on Science and Technology. The experience that I have had in industry and government has, perhaps, provided me with some unique perspectives that I would like to share with the Committee today.

The United States has, for many years, been recognized for its leadership in scientific pursuit and technological innovation. Much of this success can be traced to the role that government played in stimulating and directing these efforts mostly through the sponsorship of the Department of Defense. This role of leadership through Defense was accepted because the primary source of funding for many of the activities originated in defense oriented needs - the transistor, advanced aircraft, and many facets of nuclear technology.

Today, the roles are changing. In many areas the demands of the commercial market are the driving forces behind significant new technological innovations. This is particularly true in electronics and communications, two of the leading drivers in the world today. Now, the government finds itself in a far different position in an environment in which it is a user benefitting from the technological progress of the commercial world and not in the position of major driver and director as in the past.

The thrust in the past has also been one in which product technology was the primary focus for research and development funding. Little emphasis was given to process and manufacturing technology and in the U.S. the ability to implement many of the new technologies in commercial practice was not competitive - the result often lead to "gold plating" the final product. Recently, there has been a broader acceptance of the need for concurrent engineering in which product and process engineering are done in parallel. One must look at the total environment - the supplying industry, the specific technology of interest, and the market into which the product will be introduced. There are too many examples in which the U.S. has provided outstanding technological leadership only to have the benefit fall to others who have been more adapt at bringing the product to commercial success. Perhaps there is no better example than the video tape player - designed and developed in the U.S. - but today, with no manufacturing, all of it being done in the Far East.

While in the DoD as Under Secretary for Acquisition, I was able to initiate a number of strategic and organizational changes intended to address the discrepancies in product and process support. With the help of the present Defense Advanced Research Projects Agency leadership, organizational changes were put into place that provided a major platform for process or manufacturing research and development comparable to that enjoyed for so many years by product oriented efforts with a deputy director solely responsible for manufacturing development. It is interesting to note that the first deputy director for process engineering is now the director of DARPA, and he is continuing the appropriate emphasis. This provided top down support for the efforts underway and was strongly supported by many in industry. The next major change took place with the establishment of the Defense

Manufacturing board on a level equivalent to the prestigious Defense Science Board. This was another strong signal to industry that there was a new direction and emphasis on manufacturing and process development in the DoD. Commercially viable spin-offs from defense R&D would benefit from this new orientation.

Again, when industry first sought support for the Sematec consortium from the DoD, the effort was focused on underwriting the manufacture of one megabyte DRAMS. After extensive discussions the objectives of the consortium were redefined to focus on generic process and manufacturing technology. This was a major breakthrough - top talent, key resources were made available to the new organization and assured its success.

Now, Defense has a formidable array of manufacturing oriented programs:

SEMATEC - A consortium of semiconductor manufacturers and suppliers dedicated not to product development, but to process and manufacturing development. A corporate strategy to more nearly parallel the Japanese example.

THE NATIONAL CENTER FOR MANUFACTURING SCIENCE - a consortium of machine tool manufacturers, suppliers, and users.

MANTEC - a DoD managed program for enhancing productivity in defense manufacturing plants.

IMIP - an industrial manufacturing improvement program.

INDEPENDENT RESEARCH AND DEVELOPMENT (IR&D) - an unusual leveraged financing tool used by DoD to provide significant increase in DoD sponsored research. The conventional R&D funding for Research and Development programs which, in today's environment, must be reviewed and changed to enhance stability and long range basic investigations.

This array of programs in most cases provides a sense of commitment to the support for manufacturing capabilities enhancing U.S. competitiveness not a subsidy for industry. In all cases, industry has made at least comparable commitments of people and funds to each of the efforts.

The role of Defense has changed. The type of effort has changed. The focus on dual-use technologies is the key to affordable defense and to enhanced U.S. competitiveness in global competition. As the level of commercial product capability and quality accelerates, the benefits to defense in incorporating commercial capabilities is critical. There are some technologies such as high definition television (HDTV) that have broad use within the military, but may well not be affordable unless there is a parallel development of a large, broad commercial base. How does Defense capture the benefits of the leverage of dual-use technologies? It will be essential that Defense provide key levels of funding that will stimulate commercialization of the technologies and at the same time meet specific, critical defense needs.

For years the commercial spin-off from defense R&D has been difficult to define. This was true when primary benefits and requirements were defense exclusive. Today, commercial R&D and use often lead defense. The acquisition processes must be modified. To establish a civilian counterpart to the defense role in R&D and DARPA in particular would be counter productive. Inherent in the success that DARPA has had is the availability of a built in market - the needs of the military - to insure the presence of a critical market mass for successful fielding of the technology not only in the military, but eventually in the civilian market.

Defense is unique. It has well defined needs that drive new technology. It has a built-in market to ensure successful product introduction. It has a new role today to provide the catalyst for technological and commercial leadership for emerging technologies.

The most important change will be the development of an interdisciplinary, interagency approach to the concept of American leadership in manufacturing and technology. The initial approach to HDTV allowed both Commerce and Defense to cohost a government/industry meeting to develop a broad agenda for the exploitation of the emerging technology to meet specific defense needs, and at the same time establish the basis for a competitive posture in the U.S. marketplace.

If Defense does not aggressively support the dual-use technologies such as HDTV, it may well find itself unable to afford anything but very limited application of a technology that would otherwise find extensive use. The defense needs provide in many cases - in HDTV in particular - the critical market necessary to establish initial production facilities that again have dual-use and, which if properly implemented, would put the U.S. in a commanding lead in both military and commercial markets, as was the case in the early stages of the development of semiconductors. The U.S. is uniquely structured for the exploitation of the dual-use technologies--the military and commercial markets in the U.S. are each the largest in the world. It is time that we used these market forces working together to our advantage.

There is a critical need for senior levels of government to develop a consensus on the approach to be used with various industries and technologies in order to maintain the military and commercial leadership so important to the U.S.. Defense cannot isolate itself from the technology of the commercial market place nor from a responsibility and need to find new means to invest its resources to gain most effective leverage. The issue is compounded when many of the emerging technologies may be of foreign origin. What is the role of defense and commerce in bringing new foreign technologies to the U.S.? This will be a new role for all concerned. The issue is not final assembly work or laborious machining, but the technical resources for research and technology as well. It is a global industrial base and acquisition and industrial strategies must accommodate these very real changes in the world.

Both the defense and commercial worlds in the U.S. are under tremendous pressure. In defense it takes the form, right now, of budget constraints that are exposing many years of bad habits in acquisition and weapons systems design. In the commercial world, it comes in the form of international competitiveness that makes our traditional U.S.

technology leadership seem inadequate to maintain leadership. Both worlds have to respond, and in many ways the responses will be similar.

Both have shown a lack of emphasis, if not disdain, for manufacturing. It's been an add-on to the product design, not an enabler of it. DoD has been notorious for emphasizing performance to the exclusion of producibility. U.S. manufacturers have fallen years behind in integrating design of a product with its production. As we now know, attention to design for manufacturing, and to optimizing the manufacturing processes themselves, can produce both high performance and low cost products.

There are no deep secrets to manufacturing success--except to set as an initial goal the efficient production of a product. Right from the design stages. DoD should be trying to get its own house in order, through sensible acquisition practices that recognize the efficiencies of the commercial marketplace and the practicality of using commercial technologies, and through a highly visible, highly serious, aggressive emphasis on engineering for producibility. There are important new opportunities at hand now, as manufacturing becomes more and more dominated by information technology from start to finish, for us to bring new talent and new approaches to this area.

There is need in this country for leadership across the board, for a real commitment to next-generation manufacturing and to moving technology back and forth between the defense and commercial worlds. The role of the DoD in continued support for the variety of dual-use technologies is critical. The Department of Defense and Department of Commerce must establish cooperative long-term strategies to enhance U.S. military and industrial leadership. Not to pick winners and/or losers, but to ensure that the U.S. industrial base has every opportunity to continue in the lead.

Senator ROBB [presiding]. Thank you, Dr. Costello.

Senator Gore is going to take the first vote, and I am going to catch the end of the vote so that we can continue this particular hearing this morning.

Our final panelist is Dr. Richard Anthes, President of the University Corporation for Atmospheric Research.

Mr. Anthes.

STATEMENT OF DR. RICHARD A. ANTHES, PRESIDENT, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

Dr. ANTHES. Thank you, Senator. As long as we are establishing our relationships with the people in this room, I would like to acknowledge that I was raised in Virginia and spent the first 17 years of my life there. So I guess I do have a connection.

Senator ROBB. Your qualifications are well established. Please proceed.

Dr. ANTHES. It is encouraging to me and many scientists that you and others in the Congress have taken a deep and long-term interest in our environment and in the science needed to understand, predict, and protect it. It is really a daunting task for me to try to summarize in just a few minutes the state of environmental sciences and the importance of the environmental science, given its increasing breadth and complexity.

I did a rough estimate that probably over 100 million words have been written on issues related to the environment in this year alone. So I will just make a few remarks on my perspective on the state of the environment itself, the state of environmental science, a few remarks on the opportunities and needs for the future, and some remarks on the priorities. I will rely heavily on examples with which I am most familiar.

As you know very well, there is a perception among leaders around the world that global threats to the environment now rank along with the threat of nuclear war, at the top of today's human agenda.

In a recent article in Foreign Affairs, Jessica Matthews argued that the time is right to redefine national security; to take into account the terrifying threat of a global environmental disaster.

Just to give one example: The specter of millions of environmental refugees, with no place to relocate, looms as a major threat to global peace.

Indeed, without a stable and, generally, benign environment, economic and military security will be impossible to maintain.

Concerning the state of the environment, there is an increasing and a rather widely-held perception among scientists, policymakers, industry, and the general public that something is terribly wrong. The global environment is under increasing assault and is suffering more with every passing year.

Local and regional pollution, destruction of the earth's ozone shield, seemingly increased frequency of both natural and human-induced environmental disasters, such as heat waves, droughts, floods, hurricanes, severe storms, hazardous waste incidents, extinction of the species, deforestation, and the list could go on and on.

It is important to note, although it is a sensitive issue, that the global change is direct global consequence of the population explosion. Unless this nearly exponential growth of people can be slowed and eventually stopped, all other activities designed to slow or adapt to changes in the environment will be futile. An exponential growth cannot be sustained in a finite system.

I would like to make a few more remarks now on the state of environmental science.

The study of the global environment is an important scientific enterprise for at least three reasons.

First, environmental science allows us to develop methods to both observe the individual components and the totality of the present environment, and observe it and monitor its changes. It also allows us to predict changes in the environment on time scales ranging from the occurrence of severe storms to inter-annual climate variability associated with such events as the El Niño.

And we hope soon to predict or make refined estimates of climate change over the next decades and longer.

Second, environmental science leads to the development of new technologies for dealing with environmental hazards. The development of Doppler radars, for example, can provide aircraft with life-saving information on deadly wind shear, as demonstrated by recent tests carried out at Stapleton International Airport by the National Center for Atmospheric Research, where installation of a test system there has saved at least two commercial aircraft, in separate incidents, in the summers of 1988 and 1989.

And finally, the science of the interacting atmosphere, oceans, ice, land surface, biosphere is one of the most intellectually exciting and challenging areas of research. The system operates on time scales as short as milli-seconds to as long as four-and-a-half billion years, which is the age of the earth. Understanding this system, with its wealth of negative and positive feedbacks, is, thus, a great and intrinsic intellectual interest, as well as being essential to maintaining the habitability of the planet.

Great opportunities have been opened up by scientific advances, particularly since the 1950s, made possible by this Nation's foresighted investment in science.

Just to cite one example: Research in paleoclimates at the universities and research labs has revealed much about the environments of the past. And this paves the way for understanding the present and future environments.

However, while major progress in understanding the global environment has been made, there is much more to be learned, and there are great uncertainties in what we do know.

For example, the best models of climate in institutions around the world agree that it is very likely that in the next 50 years, the average earth's temperature at the surface will increase by, between two degrees Fahrenheit at the low end of the estimates, to 10 degrees Fahrenheit at the high end of the estimate. This is an enormous range of uncertainty. The low end of the range would be of considerable significance, but the upper end could bring on a catastrophic change, leading to a climate unlike any climate that has ever been experienced by human civilization.

Not only is the range of uncertainty in this one number very large, but the uncertainty in regional climate changes, where the impacts are likely to be the largest, are even more uncertain.

Models suggest that the frequency of extreme events, such as hurricanes, will increase, if the global climate warms.

Models also suggest that changes in temperature and rainfall will be much greater over regional areas—say, the size of the state of Iowa—will be much greater than changes over the globe as an average.

So there are great uncertainties in what may happen on small regions, where change would affect us most.

While there are many new promising ideas and new technologies, there are barriers to urgently-needed acceleration in understanding and predicting environmental change. These include: Flat or declining Federal support for basic research in certain areas of critical importance to the environmental science, particularly the support of facilities, such as super computers, radars, research aircraft, the research ships.

There are many new ideas. There are many ideas that could be implemented and tested right now, but for lack of the requisite resources.

Super-computer facilities, which run the best climate models that we have, for example, are saturated, and many promising, new experiments that could be done on the computers are not being undertaken for lack of increased super-computing resources.

While I disagree with parts of the George C. Marshall Institute report on global change, I agree entirely with their recommendations that an investment of $100 million for super-computer resources in the United States would be a very wise investment, given the fact that billions of dollars are being put on the table, impacts related to possible legislation affecting industry.

The United States could do much more in the areas of applied research and technology transfer. Applied research in the mission-oriented agencies has been severely reduced to research institutions and universities, for example, and as a result, contacts between these agencies and the academic research community have deteriorated.

Now, an all too rare example of an effective application of basic knowledge, is the use of Doppler radar to promote aircraft safety during wind-shear episodes, as I mentioned earlier.

In this example, basic research, sponsored by the National Science Foundation, was translated into a very effective, applied system, by using research funds from the F.A.A., and others.

I would like to make an analogy on where we need to go in terms of developing a prediction system for the global environment.

As a result of resources spent in the last 20 years in scientific efforts, major progress has been made in improving weather prediction of such events as hurricane Hugo. While the disaster was extreme in South Carolina, unfortunately, this last week, without the very accurate warnings, the very accurate forecast of the Hurricane Hugo, in terms of the landfall at Charleston, the loss of life could have been orders of magnitude greater than actually occurred.

We need to develop a similar system for predicting global environmental climate and regional climate change.

It is also imperative that industry be a partner in developing appropriate actions for dealing with environmental change. Corporate America must both plan for significant climate change, and must also plan for dealing with governmental laws and incentives.

The impacts of global change will result in both winners and losers in corporate America. The visionaries within industry will develop strategic responses to take advantage of opportunities presented by this challenge.

An example of a country which exports profitable products in the environmental technology is Vaisala in Finland.

Finally, I would like to say a few words on research priorities.

The Nation faces a paradox in that the exciting scientific opportunities across all disciplines far exceed the ability of the nation to support all of the proposed initiatives at the levels justified by their scientific merit alone.

Professor John Dutton of the Pennsylvania State University, and Lawson Crowe of the University of Colorado, in a recent article in American Scientist, have proposed a mechanism for the difficult task of judging priorities across disciplines. They have classified research opportunities into three general categories: Mandatory efforts related to health, environment, and national defense; grand initiatives offering revolutionary new intellectual vistas, such as the planned mission to Mars; and incremental efforts that are essential parts of the steady, forward progress of science.

They cited the super-conductor, super-collider, the mapping of the human genome, and the space station complex, as examples of this latter latter category.

So the choices, the difficult choices, must be made not only on the basis of scientific merit alone, but also on the benefits and programmatic concerns of the science, including the feasibility and readiness of the initiatives, existence of the appropriate infrastructure, community commitment, international implications, and cost.

In the area of global change, we must develop, as rapidly as possible, an ability to reliably predict the main features of the global environment, so that we can predict future climate change on a regional basis.

The strategies of NASA's earth-system science, the Global Change Committee of the National Research Council, and the International Geosphere/Biosphere programs are all important parts of this effort.

In terms of research priorities in the global-change program, the recent Committee on Earth Sciences' report, "Our Changing Planet," the fiscal year 1990 research plan offers a sound basis for developing national and international policy.

Finally, I would just like to mention some of the ingredients of a global solution to the environmental problems: Population growth must be stopped; peace must prevail; all must have access to food, shelter and education; we must develop energy-efficient technologies; toxins and substance abuse must be stopped; pollution must be arrested; non-renewable resources must be conserved.

A simultaneous solution to all of these problems will require an increased attention to environmental science, technology advances, and courageous political action on the parts of the leaders of the world.

Thank you, Mr. Chairman, for this opportunity to testify.

[The statement and questions and answers follow:]

STATEMENT OF RICHARD A. ANTHES, PRESIDENT, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

Thank you, Mr. Chairman, for the opportunity to appear before you and members of the Subcommittee today.

My name is Richard A. Anthes, and I am President of the University Corporation for Atmospheric Research headquartered in Boulder, Colorado. The University Corporation for Atmospheric Research (UCAR) is a consortium of 58 institutions of higher education in North America. UCAR includes virtually all U.S. universities with Ph.D. programs in the atmospheric, oceanic and related sciences. The consortium has been in existence for 30 years, and is organized as a private non-profit Colorado corporation. A list of our 58 member institutions is attached to this testimony.

UCAR operates the National Center for Atmospheric Research (NCAR) under the sponsorship of the National Science Foundation, the Institute for Naval Oceanography under the sponsorship of the U.S. Navy, and conducts other programs with Federal and some private support to advance the nation's research and technology efforts across a broad range of interdisciplinary environmental science.

It is encouraging to me and many scientists that you and others in the Congress have taken a deep and long-term interest in our environment, and in the science needed to understand, predict, and protect it.

It is a daunting task to attempt to summarize the state of the environmental sciences in a few pages, given its breadth and complexity, but I will do my best to convey to you my thoughts on the subject. Probably well over 100 million words have been written on this topic in this year alone! My remarks will be directed to a review of the state of the environment itself, the state of environmental science, opportunities and needs for the future, and priorities for the environmental sciences. Because the time for the oral testimony is brief, I will summarize only some of the most important issues, and will rely heavily on examples with which I am most familiar.

2.0 Global Environmental Security

As you so well know, there is an increasingly strong perception among scientists and leaders around the world that global threats to the environment rank along with the threat of nuclear war at the top of today's human agenda. Some have even expressed the view that the present widespread recognition of the tragedy that would result from all-out nuclear war lowers the probability of such a disaster. Recently, Jessica Tuchman Mathews argued in a powerful paper in *Foreign Affairs* that the time is ripe to redefine national security to take into account the equally terrifying threat of a global environmental disaster. For example, the spectre of millions of environmental refugees with no place to relocate looms as a major threat to global peace. Perhaps the increasingly widespread public perception of this threat, as evidenced by hearings such as this, will similarly lower the probability that we will inadvertently trigger such a disaster.

Thus, development of strategies to cope with environmental threats correctly commands an extremely high priority in political thinking. The attention has reached to the top leadership of the two superpowers, as well as sweeping through the leadership of many of our Western allies, among them Great Britain, France, and Norway. President Gorbachev, for example, has just announced plans for a high level discussion of this issue in Moscow, January 14-20, 1990. The world's leaders are beginning to think of global environmental security as at least as important, perhaps even more so, as economic and military security. Indeed, without a stable and generally benign environment, economic and military security will be impossible to maintain.

3.0 State of the Environment

There is a widely held perception among scientists, policy makers, industry, and the general public that our global environment is under increasing assault and suffering. Local and regional pollution, destruction of the earth's protective ozone shield, and a seemingly increased frequency of both natural and human-induced environmental disasters such as heat waves, droughts, floods, severe storms, hazardous waste incidents, oil spills, garbage disposal problems, pollution of local water supplies and the oceans, deforestation, and extinction of species, to name only some examples, all demonstrate the violence we are inflicting on our air and water support system. You are well aware of the increasing concentrations of radiatively active "greenhouse" gases such as carbon dioxide and methane in the atmosphere, and the likelihood that these increases will cause significant climate changes in the next few decades. To me, these examples indicate that the explosively growing human population and the increasing consumption of resources per person is now stressing our finite planet in visible and significant ways on a global basis---we are increasingly fouling our own nest. The present global population of 5 billion is likely to double in as few as 40 years, adding to the mounting stress on our environment. Global change is a global consequence of the population explosion. Unless this nearly exponential growth of humans can be slowed, and eventually stopped, all other activities designed to slow or adapt to changes in the environment will be futile. Thus, in my opinion, stabilizing the global population should be a top priority issue in dealing with the environment.

4.0 State of Environmental Science

Study of the state and evolution of our global environment is an important enterprise for science for at least three reasons:

First, environmental science allows us to develop methods to **observe** both the individual components and the totality of the present environment. It also allows us to **predict** changes in the environment on time scales ranging from the occurrence of severe storms, to interannual climate variability associated with phenomena like the El Niño, to climate change over the next decades and longer. More accurate predictions of weather and climate can save lives and property on short and long time scales, can make adaptation to inevitable changes in the environment easier and less stressful, and can foster economic efficiency and saving of precious natural resources.

Second, environmental science leads to development of new technologies for dealing with environmental hazards, again on both short and long time scales. Development of Doppler radars, for example, can provide aircraft with life-saving information on deadly wind shear, as has been shown by recent tests carried out at Stapleton International Airport by NCAR. Development of new strains of plants, resistant to extreme environmental conditions, is necessary to prepare for possible climate changes.

Finally, the science of the interacting atmosphere, oceans, ice, land surfaces, and biosphere is one of the most intellectually exciting and challenging areas of research. The system is highly interactive and contains important processes that occur over space scales ranging from the size of molecules to meanders in the jet stream which approach the circumference of the planet. The system operates on time scales as short as milliseconds to as long as 4.5 billion years -- the age of the earth. Understanding this system, with its wealth of positive and negative feedbacks, is thus of great and intrinsic intellectual interest, and, indeed, is essential to maintaining the habitability of the planet.

Great opportunities have been opened up by scientific and technological advances since the 1950's, made possible by this nation's foresighted investments in science. For example, research in paleoclimates has revealed much about environments of the past, paving the way for understanding of the present and possible future environments. There have been enormous advances in computers and observational systems, including satellites, radars, aircraft, and instrumentation for measuring "greenhouse" gases. Development of new mathematical methods for simulating and predicting interactive nonlinear systems have led to the ability to simulate past and present climates with some realism, and has led to enormous progress in weather prediction.

While major progress in understanding the global environment has been made over the last decade, there is much more to be learned. For example, most climate scientists now agree that for a doubling of the greenhouse gases, which is likely to occur in about 50 years, the global mean temperature will increase from between 1.5° C to more than 5.5° C, with a most likely range of 2-4° C. Even this degree of agreement, however, underscores an uncertainty of enormous significance. While the low end of the range would be of considerable significance, the upper end could bring on catastrophic change, leading to a climate unlike that ever experienced by human civilization. Importantly, even the change at the small end of the range, if it occurs over 50 years, would represent a rate of change more than 10 times faster than ever before experienced by human civilization.

If the range of uncertainty in the projected average global changes is disturbing, the uncertainties in possible climate changes on a regional basis, say the area of a medium-sized state like Iowa, are even greater. And it is changes over areas this size and smaller where the impacts on people, plants and animals are likely to be greatest. Models **suggest** that the frequency of extreme events such as hurricanes, floods, and severe storms may increase with global warming, as the hydrologic cycle intensifies due to increased evaporation and precipitation. These events typically affect regional and smaller scales. Models also **suggest** that changes in temperature and rainfall may be much greater over regional scales than over the globe as an average. Yet, because of many difficulties in the models, we have only a shadowy preview of what the decades ahead may hold. These difficulties include lack of understanding of basic physical, chemical and biological processes and their feedbacks and inadequate computer power to resolve the earth on a regional basis. Efforts such as S.1067 and other similar initiatives you have supported and proposed, Mr. Chairman, can help promote the advances necessary to resolve these matters.

Although there are many promising ideas and new technologies for accelerating our pursuit of understanding of the environment, there are serious barriers to this urgently needed acceleration, in spite of the intense interest and concern among scientists, the public, the Administration, and the Congress. These include flat or declining Federal support for basic research, including support of **scientists** and **facilities**, declining number and quality of **students** interested in the environment, inadequate support for **applied research**, and inadequate **technology transfer** of intellectual progress into technologies that can help us better predict environmental change better and adjust to it more easily. Let me cite a few examples of these barriers to more rapid progress.

In the atmospheric and oceanic sciences, which are key components in understanding the environment, support for basic research at the universities and national centers has actually decreased in real terms over the past five years. Observational facilities, including research ships, research aircraft, and in-situ sensors have not been maintained and upgraded adequately, and many new exciting systems, for which the theoretical basis is well known, have not been developed solely for lack of the requisite resources. Supercomputer facilities at NCAR and other national laboratories, which are essential to support the large models of environment, are saturated, and many promising new simulations of the earth system that could be started now cannot be undertaken because of inadequate supercomputer resources. Even though I disagree with parts of their report, I agree completely with a recent recommendation from the George C. Marshall Institute that "procurement of top-line supercomputers for the major greenhouse forecasting groups could significantly diminish the level of uncertainty in the greenhouse forecasts by improving the treatment of clouds and oceans," and that the investment of $100 million for this purpose "would be cost-effective when viewed in the perspective of the large and potentially negative impact on the five-trillion dollar U.S. economy, that could result from a premature decision based on inaccurate and possibly misleading forecasts." (*Scientific Perspectives on the Greenhouse Problem*, George C. Marshall Institute, Washington, D.C., 1989).

In the education arena, the declining number and quality of students in math and science, including environmental science, is well known. Of parochial concern for the United States is the fact that foreign students comprise an increasing percentage of students at the graduate level. It is also difficult to retain the best scientists and engineers in universities and research laboratories because of competition with industry. For example, during the first three years of a major Geoscience Research Program at Colorado State University, three of the four outstanding computer science/electrical engineering students who were working on Environmental Research problems in multi-disciplinary groups left their graduate studies to accept career opportunities in computer and other industries. The net result is a concern that the educated and trained human power may be inadequate to meet the research tasks ahead (Attachments 3 and 4).

The United States could do much more in the areas of **applied research** and **technology transfer**. It is indeed important to improve the scope and quality of research in science and technology. But healthy social progress also requires that improved technical knowledge and scientific understanding be used effectively to benefit society. All too often, the United States has expended funds in research -- and then allowed another country to reap the benefits of the research investment. A good example is earth remote sensing. The land remote sensing program in the United States is dying -- while the program overseas (e.g. Satellite Probatoire pour L'Observation de la Terre (SPOT), in France) is flourishing using technical systems developed, but never used, by the United States.

U.S. scientists must now pay $1,000 to $2,000 per SPOT data tape, and each tape contains only a tiny fraction of the data that could be productively analyzed.

Closer interaction must be encouraged between the academic/research community on the one hand and industry and government on the other. In the Federal government during the last decade, applied research in mission-oriented agencies has been severely reduced and, as a result, contacts between these agencies and the academic/research community have deteriorated. In addition to strengthening basic research, we need more federally sponsored applied research -- designed to improve the use of advances in basic science. (One rare example of effective application of basic knowledge is the use of doppler radar to promote aircraft safety during wind shear episodes at air terminals as mentioned above. Basic research in doppler techniques at NCAR, sponsored by the National Science Foundation, has probably already saved lives at Stapleton airport, and will soon be applied to increase the safety of air travel elsewhere, with the help of applied research funds from the FAA and others.)

An example of an opportunity to translate improved basic scientific knowledge and advances in observational and computational technologies into useful operational systems, for enormous benefit to the United States, is in the area of operational weather forecasting and severe storm prediction. There is considerable evidence that significant advances in the prediction of catastrophic weather, including hurricanes, tornadoes, hail, flash floods, and severe squall lines is possible. The beneficial effect of improved warnings of such cataclysms to the saving of life and property are obvious. The most recent example of this is Hurricane Hugo. Warnings were credited with reducing the potential effect of the catastrophe on Charleston, South Carolina. But not enough attention is devoted to the effective use of weather information on a daily basis to make our overstressed systems of transportation, energy production and distribution, and commerce more efficient.

Because of the growing importance of mesoscale weather, the United States is spending billions of dollars to modernize its civil and military weather observing and prediction capability. There is need for an expanded research program to learn how to best use the evolving system to improve mesoscale weather prediction -- as well as to learn how to use improved predictions more effectively to increase the efficiency of industry and business. These efforts are not unrelated to global climate warming; understanding these energetic systems is necessary for improved climate models and, as mentioned earlier, there is evidence that the frequency and intensity of extreme mesoscale weather events may increase with global warming. Even with no change in frequency or intensity, the impacts of these events are likely to be much greater in a world of increased number of people and societal complexity.

It is imperative that industry be a partner in developing appropriate actions for dealing with global environmental change. Corporate America must plan for both significant climate change and for dealing with government laws and incentives. It must also develop new technologies aimed at constraining and adapting to climate change. Corporate leaders have the opportunity to participate with the academic/research community in constructive solutions to global environmental problems.

In our efforts to influence the private sector strategy for global climate change, early involvement and consultation with industry is necessary. The following points will assist in entraining Corporate America.

- The U.S. currently leads in the knowledge base needed to respond to the challenges of environmental change. This provides us a competitive edge in the development and marketing of goods and services which will encourage corporate participation.

- From a self-serving perspective, incentives are needed which will promote actions necessary to respond to the problem. Such inducements might include, but not be limited to, tax-breaks and public exposure which would stimulate corporate interest.

- Modifications of antiquated regulatory policies will be necessary to ensure active collaboration among U.S. Corporations, universities, government research centers, and private research institutions.

The impacts of global change will result in both winners and losers in Corporate America. The visionaries within industry will develop strategic responses to take advantage of opportunities presented by this challenge. New weather prediction and warning technologies, for example, can be profitable export products, as Vaisala air sounding systems are for Finland. A major question is whether the

United States will lead or follow internationally since it is my belief that those countries that lead will be the winners internationally.

Environmental scientists and policy makers must learn to communicate more effectively. Policy makers must learn to push back their short-time horizons on a more consistent basis and accept the need for developing longer-term solutions, which must include long-term, steady-state funding to promote the necessary science and technology advances. The search for quick scientific fixes in the environmental science arena must be given up.

By the same token, leading scientists must learn to appreciate the short-term pressures present in our policy making and political structures, and respond in a more learned and practical way. Perhaps the greatest hidden challenge for our political and scientific cultures today lies in this statement. And within this fundamental need are the seeds of solutions to our global environmental crisis.

Finally, there is a difficulty in the way Federal research programs and institutions are funded. In the current appropriations process there is direct competition between basic science and popular social programs. This competition has resulted in funding for science at levels well below the President's request. A better balance must be struck; it does us little good to emphasize social spending if in the process we continue to lose international leadership in science and technology (Attachment 5).

5.0 Establishment of Research Priorities

The nation faces a paradox in that the exciting scientific opportunities across all disciplines far exceed the ability of the nation to support all of the proposed initiatives at the levels justified by their scientific merit alone. Frank Press has urged the scientific community to establish priorities for increased Federal support across scientific fields. John Dutton (The Pennsylvania State University) and Lawson Crowe (University of Colorado), in a recent article in *American Scientist* have proposed a mechanism for this difficult task. They classify opportunities into three general categories of scientific initiative--**mandatory efforts** related to health, environment, and national defense; **grand initiatives** offering revolutionary new intellectual vistas (such as a manned mission to Mars), and **incremental efforts** that are an essential part of the steady forward progress of science (they cited the superconducting supercollider, mapping of the human genome, and the space station complex as examples of incremental efforts). Difficult choices among the many possible initiatives can be made on the basis of scientific merit, social benefits, and programmatic concerns, including the feasibility and readiness of the initiative, existence of an appropriate infrastructure, community commitment, international implications, and cost. Some system to establish national priorities across scientific disciplines must be established.

In the area of global change, we must develop, as rapidly as possible, an ability to reliably predict the main features of the global environment that will prevail in the future. Over the past few decades, we have made remarkable progress in developing and applying observational and modeling systems to improve our ability to predict events like hurricane Hugo, and these efforts have paid off handsomely. What we are completely lacking at this time is an observational and modeling system to tell us what is likely to happen to the global and regional climates over the next 10-50 years. To obtain this predictive capability, we must dramatically improve our quantitative understanding of the Earth System and the many interactions and feedbacks that control its structure and evolution. The main outlines of a scientific strategy that will be effective have been laid out by NASA's Earth System Science Committee, by the Global Change committee of the NRC, and by the International Geosphere-Biosphere Program (IGBP) planning effort.

Certainly we need the global observation system -- Mission to Planet Earth and the Earth Observing System -- now being created by NASA and its international partners. A global data system for global change research and Earth System modeling is the heart of the effort and must be given high priority.

We need vastly improved national and international data communication networks to transport data and information and create the distributed, interactive, interdisciplinary scientific environment required for progress. And we need, immediately, a greatly enhanced supercomputer capability if we are to be able to simulate the evolution of the Earth System with the resolution and fidelity that will permit regional impacts to be foreseen.

All of this will cost one or two billion dollars a year -- or more -- but perhaps that is not so large when we recognize that the Department of Defense spends nearly a billion dollars a day.

Earth System Science is already creating a new paradigm for the science of the Earth, and we must speed that process with new partnerships between government, academe, and the private sector. We need to find improved methods to support interdisciplinary research, and yet we must enhance the strength of the disciplines that provide the foundation of basic knowledge needed to support Earth System Science.

As you know, the United States is developing a U.S. Global Change Research Program that covers many of the research issues I have addressed here. The recent report of the Committee on Earth Sciences, Our Changing Planet: The FY 1990 Research Plan focuses on establishing a sound scientific basis for developing national and international policy on global change issues. The scientific objectives are to monitor, understand, and ultimately predict global change. The CES has done a good job in describing the program and the scientific priorities, and I urge support for this comprehensive program.

6.0 Ingredients of a Global Solution

Most people who study the issue of protecting the global environment conclude that the global ecosystem cannot be stabilized and the global warming threat eliminated unless a totally integrated system solution is achieved. The solution must include both lessening the magnitude of the human activities that cause global change, and development of strategies to adapt to the changes that cannot be averted. Piecemeal efforts are unlikely to succeed. Among the issues that must be resolved for a satisfactory accommodation to the future world, even in the unlikely event that climate were to remain unchanged, are the following:

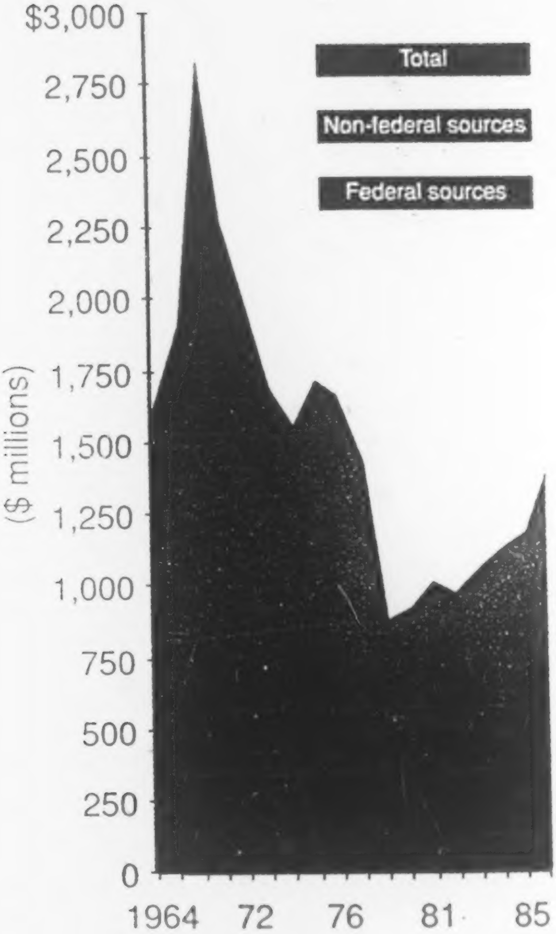
- population growth must be stopped;
- peace must prevail;
- all must have access to food, shelter, and education;
- energy-efficient technologies must be developed;
- new technologies, like halophytic agriculture and genetic engineering and alternative energy sources, must be created;
- toxins and substance-abuse must be controlled;

- pollution must be arrested;
- waste must be made a resource and recycled;
- non-renewable resources must be conserved;

A simultaneous solution to these problems, which will necessitate establishment of national priorities and cooperation among nations on a scale never before attempted, will require increased attention to environmental science, technology advances, and courageous political action on the part of the leaders of the world.

Thank you Mister Chairman, for this opportunity to testify on these issues.

Attachment 2



Federal investment in research facilities declines.

Source: The Coalition for National Science Funding
"Investment for the Future", 1989

Attachment 3

STUDENT ACHIEVEMENT IN SCIENCE: HOW DO WE RANK?

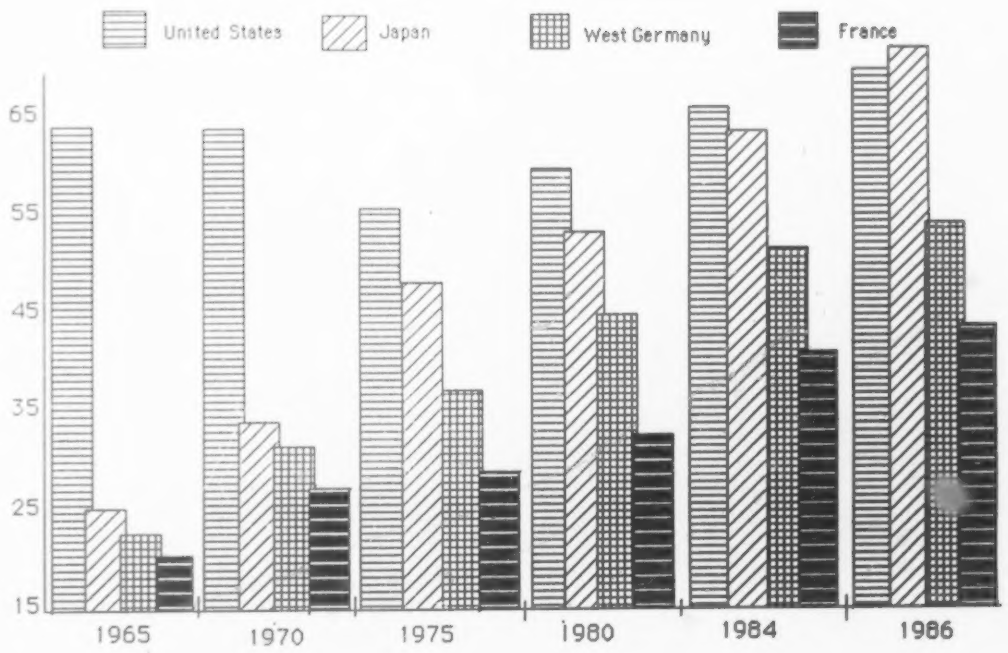
Source: International Association for the Evaluation of Educational Achievement, 1988

			Grade 12/13		
Country	Age 10	Age 14	Biology	Chemistry	Physics
Australia	9	10	9	6	8
Canada	6	4	11	12	11
England	12	11	2	2	2
Finland	3	5	7	13	12
Hong Kong	13	16	5	1	1
Hungary	5	1	3	5	3
Italy	7	11	12	10	13
Japan	1	2	10	4	4
Korea	1	7	-	-	-
Netherlands	-	3	-	-	-
Norway	10	9	6	8	6
Philippines	15	17	-	-	-
Poland	11	7	4	7	7
Singapore	13	14	1	3	5
Sweden	4	6	8	9	10
Thailand	-	14	-	-	-
USA	**8**	**14**	**13**	**11**	**9**

Attachment 4

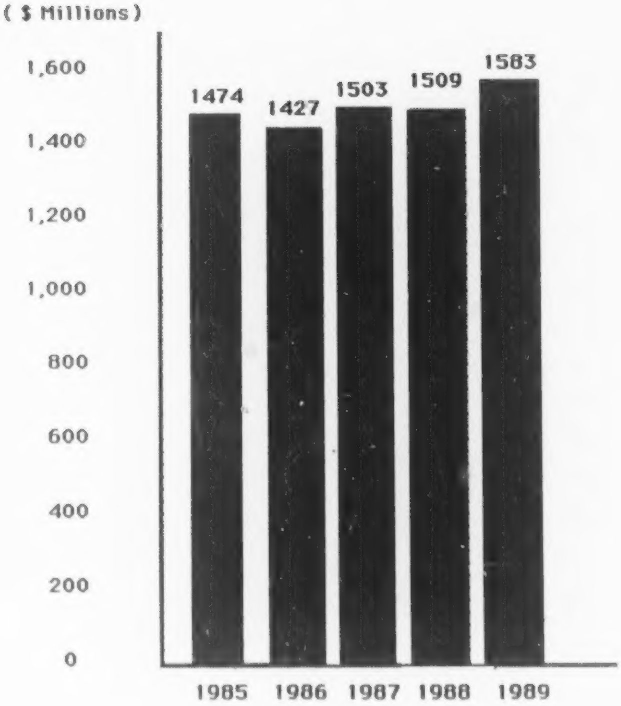
R & D Scientists and Engineers per
10,000 Workers

The fraction of the population engaged in science and engineering has remained constant in the U.S. since 1965, while tripling in Japan and West Germany



Source: The Coalition for National Science Funding
"Investment for the Future", 1989

Attachment 5



The NSF Research and Related Activities budget has not grown significantly in the past 5 years

Source: The National Science Foundation

QUESTION OF SENATOR KERRY AND THE ANSWER THERETO

Dr. Anthes: The health of our planet is increasingly threatened. As you point out in your testimony, science has enabled us to better understand our environment and the threats to it. Many of these threats are international; how can we best develop science and technology policy to coordinate with other nations to address these problems?

Answer to Senator Kerry's question

Science and technology have indeed identified potential threats to the health of life on earth. With each hazard, there is a degree of uncertainty that needs, so far as possible, to be reduced by additional research and monitoring. Many of the threats, as Senator Kerry's question indicates, are international.

For many threats, there are numerous possible policies and actions, local, national and transnational, that can help protect against the threats or provide insurance that will counter their impacts if indeed the threats cannot be averted. Prudent people usually are prepared to commit resources if they understand the risks and if the resources provide even partial relief in worst case situations. This is done even in the face of large uncertainties about the reality of the threats. Military preparedness is a prime example. But we should also develop policies and strategies to provide insurance against environmental risks of droughts, crop failures, hurricanes, earthquakes, disease, etc., even if there are significant uncertainties with each of these risks.

With respect to science and technology policies and actions to meet threats to life on earth, I commend actions analogous to those undertaken to meet the threat to the stratospheric ozone layer from CFC's through the US role in the Montreal protocol. To be sure, the greenhouse warming threat is far more pervasive and the possible steps to meet the threat are vastly more complex. Among the possible policies and actions to consider, in my judgment, are:

(1) U.S. support of national and international family planning efforts, consistent with religious and moral values of different peoples and cultures.

(2) Establishment of levies against greenhouse gas emissions at the source. Use the revenue to create a trust fund for research and technology emplacement for emission reduction and for research and technology enhancement for measures to adapt to possibly inevitable changes wrought by the global warming. Examples of such adaptive technologies include the development of cereal crops grown with seawater irrigation; genetic engineering for heat tolerance in food crops; exploration of gene pools for promising but unexploited food and fiber crops, including both plant and animal species, that will provide high yields, pest resistance, and chemical tolerance, with particular emphasis on tropical species.

(3) Development of international standards for energy efficiency, toxic emissions, greenhouse gas effluents and other environmental threats that depend for their control on international cooperation.

(4) Provision of tax and other incentives for installation of industrial and domestic machinery and practices that promote recycling of waste, reduction of water demands, enhancement of energy efficiency, etc. Highest priority actions are those that provide economic benefits to offset their increased costs even if no climate change occurs, and that provide insurance returns if the global warming is severe. It is especially important to develop strategies that benefit the doer, even if universal participation is not achieved. Energy efficiency developments, for example, are in this category.

(5) Support research for understanding and predicting global climate change. Accelerated research is important to help guide policy and make it easier to adapt to relatively rapid changes in climate and the environment that may be inevitable.

(6) Establish new consultative mechanisms to create policies and strategies to bring about integrated system approaches to the elimination of poverty at home and abroad and to enhance active participation of the third world in the benefits of the economic development without further degradation of the environment.

This is obviously a partial list. We will be happy to join in further discussions to flesh out the kind of positions that could lead to U.S. leadership in bringing about global environmental enhancement within the framework of a world that is peaceful, cleaner, and fairer.

Senator GORE [presiding]. Thank you very much, Dr. Anthes. I am going to hold off my questions. I just came from the vote; Senator Robb's going to have to go over there, and I am going to recognize him first.

Senator ROBB. Thank you, Mr. Chairman. I see that all the lights are up, so I am going to have to probably leave before I get the answer to just one question I would like to pose, particularly to Dr. Branscomb and Dr. Langenberg, if I might.

You both mentioned state efforts with respect to some of the R&D activities that are taking place.

My own state happens to be one that is now committing substantial resources to this particular effort.

I am curious, with respect to coordination at the Federal level of state R&D efforts, how necessary is it, particularly given the fact that a number of those efforts probably are applied rather than pure scientific research in many cases. How might it be coordinated better? You indicated that we were tracking at one point, and we are not doing a particularly good job tracking at this point.

And a second question, if you will, in terms of stimulating this type of research and development at the Federal level, what kind of a mix, in terms of matching grants that the Federal government provides, as well as the state government and the private sector, make for the most effective mix in bringing about the kind of research that is truly beneficial. Obviously, there is always a factor of whether or not anything is going to result in something constructive.

But what is the necessary threshold to get valuable research started, as opposed to simply providing something to do for those who might pursue will-o-the-wisp-type projects that might have, at best, a rather remote possibility of having any commercial application. This is where the greatest emphasis should be.

I am going to probably have to leave before you can finish responding—Mr. Chairman, I appreciate it.

I regret I am not going to be able to return to this morning's hearing. I will join you again tomorrow for part of the hearing.

Dr. BRANSCOMB. That is a very good question, and two comments: First, some of the most important things the states are doing are not R&D. There is R&D; R&D has a place. But I think the important thing the states are doing is, they are addressing the problem of how does a small firm get good, professional advice on how to deal with new process technology that they are scared to introduce.

How do they get help training their workers?

American firms, small firms especially, are notorious for not training their workers, compared to firms in other countries.

How do we get the two-year colleges, the vocational high schools, and the other tools that build the technical competence of our middle and lower-level technical folks, to match the economic opportunities that are there in the state?

Most of the states have fine universities. Many have some big federal installations, including military ones, all kinds of technical and management assets. Those assets are, typically, poorly coupled to the heart of the middle-sized business community on which, I think, our competitiveness depends.

I do not think it is coordination at the federal level that is most needed.

If I was a governor, I would not invite the Federal Government to coordinate my activities. I would invite the Federal Government to support it, not just with money, but, importantly, with the Federal Government's technological assets, which are substantial.

And let me just give one specific. The National Governors' Association has, over recent years, convened the leaders in each state government responsible for industrial extension and new business creation activities.

The leaders of those state groups are meeting today in Washington; Megan Jones is the one who represents Massachusetts. They are looking for an institutional home, to try to keep this group of 50 states working together.

I have suggested to them that, in fact, the old Bureau of Standards, now NIST, has a perfect pattern for doing that. It is called the National Conference of States on Weights and Measures. Later, the N.B.S. created a National Conference of States on Building Codes and Standards.

NIST does not run these associations of state officials, but what NIST does is provide the secretariat and make available all their technical knowledge. By funding the secretariat, they do provide a little indirect subsidy. But the governors appoint the delegates to this kind of an institution. It is really a clearing house for comparing their experience and voluntarily coordinating their activities.

It would be a particularly valuable thing for NIST to host, because this committee and the Congress have given NIST two very important missions: one, for regional manufacturing centers, and another for helping the states work at industrial extension.

So NIST needs to learn the details of these activities from the states, and the states need to get access to the technical muscle of the Federal Government. So I think it is a marriage made in heaven, and we ought to get on with it.

Senator GORE. Other witnesses in response to Senator Robb's question?

Dr. LANGENBERG. I would agree with everything that I have heard Dr. Branscomb say.

I think the point is not coordination; it is not guidance or control. The point is, knowing what is going on in all of our diverse 50 states, comparing information, and using that information to try to mesh federal efforts with state efforts.

State efforts will drive federal efforts and vice versa. And I think, often, in desirable ways.

And state efforts will drive state efforts.

I can assure Senator Robb that some of the good things that have happened in Illinois, for example, have been driven by knowledge of what has been done in the state of Virginia.

There is a great deal of competitiveness among our 50 states, and that competitiveness can be put to good use for positive purposes.

Likewise, many of the federal programs that are available to institutions and states, the national laboratories, the universities in the states, have served as a focus for state efforts to help those institutions gain federal support.

This can be something as simple as a matching contribution to a grant. Matching contributions are a very useful way of bringing in both states and the federal government, as partners, in a scientific effort.

It could be something as indirect and as long range as simply helping to build the state infrastructure which, ultimately, will attract federal support.

So I would agree very much with Dr. Branscomb.

We do not want to coordinate from a federal level, but we would find very useful a means of keeping track of what is going on and using that knowledge, to use the federal side to encourage and support the state side and vice versa.

Dr. COSTELLO. I think that—I am working with the state of Michigan through ERAM, which is an off-shoot from the University of Michigan. And they are looking very strongly at the role of federal R&D dollars to incorporate within the state strategic plan on technology; looking at the small firms, and how do they establish, as a state responsibility, that a coordinated plan for technology strategy, and then implementation in a wide variety of small firms, as well as some of the larger, obviously, the large automotive companies in the state.

So the states have some activity underway. Direction from the top is not what we need, but good sharing of information so we do not have—unaffordable duplication is key.

Dr. BRANSCOMB. One more specific observation.

The Federal Government is much more successful than the executive agencies though they would be with the SBIR program. And many states, Massachusetts, for example, takes excellent advantage of SBIR.

The state works with small firms through several quasi-public corporations in Massachusetts that generate their own revenue through early-venture investments. And they very often suggest the firm adopt a strategy which incorporates an SBIR application in with the local development strategy. And it has paid off in many cases.

Dr. LANGENBERG. If I could just support that, as a fan of the SBIR program.

It is commonly said that the Federal Government cannot pick winners; the market will pick the winners. And one of the great results of the SBIR program is that it has created a market that does, in fact, identify potential winners.

Senator GORE. Well, as the author of the SBIR program, I agree wholeheartedly.

Before going to my own questions, let me say that the intervention of a vote on the floor demonstrates one of the problems with federal science and technology policy.

The Federal Government has a lot of other things going on, and what I hope these hearings will accomplish, in addition to focusing attention on the discreet, selected issues we are exploring here, is to begin a process by which we might generally elevate the profile of science and technology policy.

When there are competing demands for time; when there are competing demands for attention, the Federal Government simply has to recognize how urgent this subject is.

We must find a way to focus the executive branch and the legislative branch of government on the need for significant changes in the way we approach science and technology policy.

Let me also assure you, Dr. Costello, and you, Dr. Anthes, that I have read your prepared statements very carefully. I heard the beginning of the one, and the end of the other, but I have read the full statements carefully, and I appreciate it very, very much.

Dr. Branscomb, you said that the most powerful engine of change in the world today is growth, and the most powerful engine of growth is technology. The base of technology is science. And I agree with all of that.

One could contract the formula, and say simply that the accelerating scientific and technological revolution is the most powerful engine of change in the world today.

And we as a nation, and we as a global civilization, must make greater and more successful efforts to understand the dynamics of that revolution, and to understand the interaction of its consequences with our condition on this earth. We have not done that very well.

Our uniqueness as a species comes from our ability to construct mental models or blueprints of the world, and by manipulating those models, gain the power to change the world around us.

By improving the process by which those models are created, and by which the information out of which the models are made, is extracted from the world around us, we have demonstrated the cleverness in expanding exponentially our ability to effect the world around us.

But we have been slow to recognize the extent to which wisdom lags behind cleverness.

And like the sorcerer's apprentice, we have amused ourselves with these new powers that come out of the revolution in science and technology, without pausing to understand the consequences if we do not think the process through to its conclusion.

It is partly for that reason that we see the emerging crisis, called global climate change.

As a nation, in considering our economic competition with other nations, we have contented ourselves for too long with a superior ability, coming out of our university system, to create scientific knowledge. And we have paid too little attention to the refinement of that knowledge into useful recipes for improving the industrial and commercial processes that, together, constitute a competitiveness in this world.

We have also focused so much on the process that we have failed to pay attention to the basic skills that students now entering our education system, will emerge with.

And other nations are, obviously, doing a better job of giving those basic skills, and that basic education to their people.

And although we have defined national security in military terms for quite a long time, as Dr. Anthes says in his statement, and as others have noted, national security is acquiring a much broader definition.

But even where military security is concerned, we see, as you pointed out in your statement, Dr. Costello, that the robustness of private research and development is leading to a very different relationship between the military and the civilian sector, where important technologies are concerned.

Now how do we as a nation confront these, and other related challenges, where science and technology is involved?

Several witnesses on this panel have noted the inherent advantages of having a decentralized non-policy, if you will, affirmatively abdicating a centralized effort to direct or shape, or focus science and technology policy.

I think it is fair to say that at least a couple of our witnesses on this panel acknowledge and recognize the salient advantages of that approach, but have come to question whether or not the balance has now shifted due to the changes that the witnesses have discussed, and now point us toward a change in that non-policy. It points us toward a more focused, organized effort by the Federal Government in cooperation with states and universities, and the commercial sector, to define our objectives and needs more sharply.

Is that a fair summary of at least part of what you all were saying, Dr. Branscomb?

Dr. BRANSCOMB. Indeed, it is. I think one can summarize it in the words that Langenberg used, which is that we do not need to get caught up in what people fear under the label, "industrial policy."

Nor do we need to restrict ourselves to a passive government role. Vannevar Bush recommended, in his famous report, not only that the government use an arms-length semi-governmental corporation to institutionalize what he called the National Research Foundation, but that it, have organizational units that dealt with military technology; that dealt with medical technology.

It was much more of a Department of Science in his conception. In fact, the selling job he had to do in that report was not to the Congress; it was to the private sector, and the academic community, to get them to accept this federal role.

What Senator Kilgore, who invented the name National Science Foundation, had in mind, in 1946 is what we are now struggling to figure out how to do in 1989.

I think Bush was correct at the time, in that the country was not ready for a strong, strategic national effort, led by the Federal Government.

The compromise that came out of the National Science Foundation was, in fact, a more reflexive, decentralized kind of strategy than even Bush, himself, had in mind, and he was a conservative Republican engineer—businessman, in fact.

But, may I respond to your identification of mental models or, if you like, paradigms as being important drivers of the way we do things, because, that is a very fundamental point.

I should have addressed it in my testimony, and I compliment you for mentioning it.

Because a lot of the way human society has used science and technology really derives from a tradition of linear, Newtonian thinking. There are some new ideas on the table today, which come straight out of the study of ecology—much of it from Professor "Buzz" Hollings at the University of British Columbia.

The notion is that we should use our science and technology to improve the *resilience* of society, not to try to maximize its *stability* or its *efficiency*. Nature follows resilient strategies. Mature Phenomena that cause disruption tend to be non-linear; they tend to have runaway effects. And nature adapts to abrupt change in a very natural way.

Human societies try to figure out, what do we want to maximize? We want to maximize wealth, maximize efficiency; we want to keep things the same. Nature is not like that.

Many of our human arrangements, the way we use technology in agriculture; our strategy for plant genetics; our strategic nuclear balance, are all designed to maximize stability at an enormous price of resilience.

There is a need for some profound thinking about what societal arrangements will allow us to address issues of uncertainty that are inherent in a nonlinear dynamic world. Global climate change is only the most conspicuous and in some ways perhaps the most threatening example of that, but there are many others.

Senator GORE. Before you proceed, Dr. Langenberg, let me comment on what you have just said. Dr. Branscomb, there is a sense of crisis, to use an overused word, that pervades many aspects of our civilization today. We are now retreating from the brink of nuclear confrontation.

We are recognizing the unprecedented crisis of global climate change which really comes from our relationship as a species to the planet. We are seeing challenges in various societies such as the drug epidemic here in the United States, the collapse of Communism as a serious idea in the eastern bloc to name just two. The list is literally endless.

Any time you have a generalized sense of crisis there has to be a deeper cause. I would submit that as we discuss science and technology policy, we are also looking at an area where there is a kind of fault line between different ways of thinking about our role on earth and our role as a Nation. You went straight to the subject of linear thinking and how ecological thinking is different from linear thinking.

I think that is quite true and you have stated it eloquently, but there are other challenges to the intellectual model on which the scientific revolution was based. The introduction of quantum mechanics, the study of systems theories, which is similar to what you call ecological thinking, the refinement of some of those theories and the chaos theory that has been discussed so frequently of late.

In the past, whenever we have approached the general subject of science and technology policy we have done so within the same intellectual framework that produced the scientific revolution and many of the problems that we face today.

When you say we should focus on strengthening the resilience of our society, I think that is an interesting way to express a new set of goals. But if we think of science and technology policy merely as a means by which we can further streamline and turbocharge the process of harnessing the research enterprise and the cleverness of applied science to a set of specific goals that are chosen for reasons which themselves have received insufficient attention, then we are asking for even more serious trouble than we have got thus far.

What are the goals we want from science and technology? More ways to gather and burn fossil fuels even more rapidly in ever higher volumes each year? Ways to improve our ability to establish dominion over the earth? Or ways to find formulas for preserving, replenishing and protecting the earth and our relationship to it?

Similarly, if the enterprise when applied to military security is focused ever more efficiently on the effort to find even more destructive weapons, capable of inspiring and generating even more fear in the minds of our adversaries in the world, that misses the point. That is an intermediate goal designed to help us find what we call "security. 'What is our ultimate objective?

It seems to me that in any discussion of science and technology policy we have got to really focus on those longer-range goals and objectives.

Dr. Costello, I interrupted Dr. Langenberg and I will go to him, unless you want to defer. Go ahead.

Dr. LANGENBERG. Let me just make a couple of remarks expanding on Dr. Branscomb's introduction of the word "resilience. 'I think that is an excellent key word for pursuit of this discussion.

The resilience of a genetic species, as I understand it, depends a lot upon its diversity. The resilience of this Nation and one of its great strengths seems to me goes to its diversity—its ethnic diversity, its cultural and racial diversity, its political diversity.

We have got 50 states that nobody wants to coordinate into a monolith because each of these states approaches its own specific problems in a different way. One state will invent a solution that another state has not thought of which may be transferable. It may be that one of the objects of our scientific and technological policy is to increase our resilience to provide ourselves with more options.

Often what science does is to give you a new way of doing something that you need to do, or that you want to do, that is totally different from an old way of doing something that provides you with another realistic option.

It may be, rather than maximizing something—maximizing our energy production, maximizing our power to defeat the Soviet Union in case of war—we want to look, perhaps, at our scientific and technological policy as a way of helping us understand or figure out other ways to do the things that we thought we needed the energy for, or to find other options for approaching our relationships with the Soviet Union.

Dr. COSTELLO. I look at the Defense Department, since my immediate experience was there, and being a catalyst and the Executive Branch, by providing consistent leadership, can create an environment that is substantially different.

I think we have pretty well demonstrated that we have ultimate kill capabilities. I think we have to look at other things the Defense Department can do, and I would like to cite two that may be of interest to you. I went to the military departments and I said, look, solid waste disposal is really a key area of concern. We have bases in every single state. We are a major landowner. We are a major producer of solid waste. What is your plan to change how we deal with solid waste?

So I looked at power generation systems and the use of reclamation and recycling. Everybody came back and said, but gee, that is too costly and my answer to them was, it is too costly the way you looked at it. You did not look at it long enough in the future, because you—may have to take it for 90 miles; it will be 120 miles soon, and soon you will have barges out floating around the world trying to find out where to go. The cost will be astronomical.

You have a responsibility to be a catalyst to show other people what can be done, in many cases even putting in place a capability that the surrounding environment can use. We need a consistent policy of EPA and Defense working together instead of an adversarial relationship. It is time that the Executive Branch got together on some of these things.

To take another instance—it is a little step. Admiral Trost has stated that the Navy will use electric propulsion in the year 2000, or 2010. I said, Admiral, you did not go far enough. It should have been cryogenic electric propulsion, superconductivity, because that will put us in a place where we will be world leaders in cryogenic superconductivity propulsion systems and transmission systems that will have a major impact on saving energy.

But nobody in the Navy wanted to do that, because it was a risk. They would rather continue with what they were doing, even though the economics said it might be feasible today to use superconductivity, which would have a major impact on the use of energy in this country and the world.

We have got to go to everybody and set challenging goals so that we can get consistency across the Executive Branch, and I use that term very carefully, and use the resources and the money in the Defense Department as a catalyst to get these jobs well underway.

There is no other organization that has the money, the resources and the geographical dispersion that can impact as much as the Department of Defense. So I have to go back and say, hey you guys, spend your money a little differently. Take on a responsibility for these other activities that you may have put aside or ignored because of the risk to your funding levels.

They have to take bigger picture today because the world is bigger for them today. They cannot exist by themselves.

Senator GORE. Let me take a different approach. We are focusing with this panel on the implications of big changes in the context within which science and technology policy is confronted. We have talked about a number of changes and your statements have been excellent.

I would like to take a somewhat different approach. Let us look at the U.S. effort in science and technology as a system and try to apply this nonlinear approach Dr. Branscomb referred to—systems theory—to analyze how this system has changed.

One of the new insights in systems theory, as I understand it, in the study of open systems—that is, systems where energy comes in and flows out—is that if you increase dramatically the amount of energy flowing through that system there is a tendency for the system at some threshold, to break down and then spontaneously reorganize into a higher form of complexity.

It seems to me that we have thought of science and technology policy in the same way for quite a while, and yet the amount of attention given in the private sector to this subject has increased dramatically.

Perhaps most basic of all, the amount of information that is flowing into and out of the scientific enterprise has increased exponentially.

You talked about some changes, but let us look at it for a moment just in terms of that information flow. We used to think of science and technology as a way to collect and organize information and turn it into something that was useful for people, or the country.

Have we gotten to the point where the sheer quantity of information collected is overwhelming the ability of science itself to organize it and express it in ways that can be useful to policymakers. Does that question inspire any kind of response, Dr. Branscomb?

Dr. **Branscomb**. It does indeed. I have for some 30 years advocated the notion of a science policy that is based on pulling the research and the science we need through an effective system of information flow and utilization, rather than taking the opposite view, in which society tries to create as much knowledge as we can and assume that somehow the processes inherent in science and engineering will make that knowledge available to users.

It is overwhelmingly clear that there is more useful knowledge in the world today than most enterprises or governments use. If we look at how that information system actually works in our society, we see that the scientific information system serves scientists very well. That is, they communicate with each other extremely effectively. They do not communicate terribly effectively to the people in other professions that can use the results of science.

Certain institutions in our society, for example large high tech companies that are big enough to have a corporate research laboratory, have experts who do academic-styled work in close collaboration with universities.

They—IBM, for example—are very well plugged into the academic and intellectual world. But a middle-sized, $150 million-a-year-revenue manufacturer of hydraulic valves is not well served by our public policies. There is almost nothing, at least at the Federal level, that takes the existence of those companies into account at all, and yet I think they are the heart and soul of the innovation process in America.

If you go back to 1960, after Sputnik, Hubert Humphrey, looked at this big effort in R&D which was producing huge amounts of information. He realized in 1960 that the Federal Government ought to pay attention to how this information was going to get into somebody's hand who could make good use of it.

With help from Ed We in the Legislative Reference Service Senator Humphrey pushed for the Federal Council for Science and Technology to address this issue. That led to the famous Weinberg report of the President's Science Advisory Committee published January 10, 1963, and we were off and running on a science and technology information policy.

The Federal Council set up a committee called COSATI—the Committee on Science and Technology Information. The OECD took off with these ideas. I in fact served on a high-level advisory committee to the Secretary-General of OECD and we wrote a report on science policy and policy for science in 1973.

But shortly thereafter, when Ed David was science advisor, COSATI was essentially destroyed by moving it over to the NSF which promptly changed its role. Soon thereafter, the OST was transferred down to the NSF, and ever since then the Federal Government has been dismantling whatever was left of its attention to this issue.

I very strongly welcome your interest in the National Research and Education Network. Embedded in your bill is an idea which deserves, in my view, to be the name of the bill and not simply an item in it. Namely, the provision of scientific and technological information services by a combination of profit-seeking and nonprofit institutions who are trying to serve users.

If I could just finish with a final note, I have also, for years, thought that our policy on federally-supported research was seriously inhibited by the lack of an adequate language—if you like, a mental model—for describing the different parts of the science and technology system. The Defense Department system has a pretty rational system for categorizing R&D in the budget, if they actually used it the way it was defined. The 6.1, 6.2 and so on categories do define the sequence of distinguishable kinds of activity that suggests to you how these kinds of investments are in fact going to benefit the Defense Department.

When I was Chairman of the Science Board we changed the National Science Foundation criteria for giving grants to define more strictly the words "applied research." Applied research is not the mission of NSF, and yet all of the data that NSF keeps for the civil agencies for use in the Federal budgeting process is based on a set of definitions called "basic research," "applied research" and "development."

Since you and I assume these words mean what they say, you and I would quickly agree that the Federal Government has a very limited role in supporting applied research and development for the private sector, though it may for its own missions in defense.

So we are forced by the language to say we had better stick with supporting only "basic research." But if you go to Japan and you ask a Japanese university researcher, "What is your basic research?" they will say "Well, it is this terrific work we are doing on optical processing, or it is this great new ceramics product material I have invented."

Senator GORE. Or quality control.

Dr. BRANSCOMB. During this last year there was a study made for Dr. Bloch, and I am sure he will tell you about it if you ask him, on the taxonomy of science and technology. And they are now considering—I am sure they have not decided yet—some definitions that are different from "basic," "applied" and "development." The proposed categories are defined not in terms of the motives of the investigator, which the current system is, but in terms of who is going to be the beneficial user of this information.

In fundamental research, it is the scientists who are the user; those who create it also are the users.

Strategic research is still good research, good for universities to do, but the beneficiary is some other technical discipline, usually engineering.

And then, of course, there is something called problem-solving research, which has quite specific goals and which commercial companies and the Defense Department and operating people have to do.

If the government budgeted R&D in terms of categories that express where the benefit is going to flow, two benefits might result. Number one, we might redistribute the emphasis a little bit in what fields we invest in; and secondly, we might pay a lot more attention to the pipelines through which that information flows. We might find out what those pipelines are, whether they are clogged, or are working.

Senator GORE. Let me comment on that, and then I will come to you, Dr. Costello. And I know you are anxious to say something.

That is what I was trying to get at when I said we have got to define our purposes and our goals. And we have had a heavy bias in the Federal Government's role toward the support of as much basic research as possible, the creation of as much raw data as possible. And we have avoided the difficult decisions regarding what uses are of priority to us. And how do we want to organize that effort to focus it a little bit more toward applications?

And so we have this rapidly increasing production of raw data and the sheer volume of it has implications for our ability to organize and use it efficiently.

It is almost like agricultural policy, where we subsidize the accumulation of vast grain surpluses all over the world, and the farmers like that, at least in the short term. But we avoid, in every nation, the hard decisions on how we could coordinate grain policy in order to get a more efficient allocation of effort and, in the process, help prevent the starvation of the millions every year.

With respect to science and technology, we have these vast surpluses of data; mountains of data that are not used and not understood. Ninety-five percent of all the photographs of the Earth, Dr. Anthes, taken in the LANDSAT program have never fired a single neuron in a single human brain. They are stored in surplus piles of digits. And nobody ever looks at them or even scans them for salient features.

Now, we are gearing up for the Earth Observing System. And have you seen the projections of data in the earth sciences that will come out of that program? I mean, I am all for it; I think it is our top priority in space, but how are we going to efficiently use the information it produces?

If we have only looked at 5 percent of the excellent photographs of the Earth's surface that we have now, crammed with useful data, how are we going to cope with an exponential increase? I mean the curves are staggering.

You take the total amount of all knowledge in the earth sciences today, they are going to be beaming down to the Earth's surface that amount on a regular basis.

The point I am getting to is that the organization of this data requires decisions on what we want to use it for. That, it seems to me, is the first step in making science and technology policy.

Dr. Anthes.

Dr. ANTHES. I would just like to make a brief comment on some of the things you just said. I think that the establishment of goals in science are very important. And also important are establishment of measures for judging the rate of progress toward achieving these goals.

Let me just give an example of climate research, which is something on everybody's mind. It is not enough just to double the number of grants of individuals working on climate-related projects. The libraries are already full of journal articles that even the specialist in the disciplines cannot keep up with.

What is needed, I think, are projects with goals. For example, reducing the uncertainty in our current climate projections for the next 50 years; that is a concrete goal. One can judge whether we are making progress toward that.

It takes teams of people working on projects and a multi-disciplinary team of scientists working on components of the system, but also people to integrate this knowledge, to synthesize it, to put it into a systems concept that are directed toward meeting these goals. And it takes periodic evaluation of how fast we are approaching the goals. And it takes dialogue with the people who need the information. It is not enough to say well, we will let you know in 10 years; give us a lot of money and we will let you know in 10 years how we are doing. We need an iterative process where we can supply increasingly, hopefully, precise answers to the questions you need. And then, in turn, you, the policy-makers, come back and ask additional questions.

Senator GORE. Dr. Costello.

Dr. COSTELLO. I spent a lot of time being a bridge between the scientific laboratories and the users. And I found, even in one of the largest companies in the United States, that the scientific laboratory was as isolated from the user as the university was. The university and the scientific lab got together and did a fine job, but they never talked to anybody—the user.

If you look at DARPA, DARPA has a good reputation, but if you try to start pointing out which programs in DARPA really made an impact in the weaponry that the guys in the field were using, you will find not too many.

You have got to get the user involved. You can put in all the data you need, but you have got to get the guy that is going to implement some changes in what he is doing, to work directly with you.

So what I did with DARPA, I said look, I am going to start a milestone program in DARPA. You can start off on any program you want to at milestone zero. You can come to the DARPA board of directors and you can say here is what we want to do as a scientific endeavor, and we will let you go because we think it is a good idea; basic science, basic information, it is a good idea.

And we will give you maybe a year or two years, or whatever we think is appropriate within the rational number of dollars to verify that it is a good scientific pursuit to follow. But at the end of that period of time you have got to come back to us with a user, because the user has to start being involved. I am not going to ask the user to spend any money yet, but I am going to get him involved early enough so that he has an information system and a structure to start using that information or at least being sensitive to the information.

And that may run on for another year or two, depending on how far we have to go.

When you come back for the third milestone, which we will call it in this array, the user is going to have to start putting some money into it. He has got to be committed to the use of that technology. In that case it allows DARPA to pay the user to implement this technology into his system.

And by the last milestone, the user takes over and DARPA gets out and starts over again.

The reason I go through that is that we do have excellent scientific endeavors in proliferation around the country. But we do not have the mechanism in place—all right, I will say—to force the use of that in a logical way, to structure a mechanism and a process for the user to be involved early enough so he can not later on say well, hell, that was a nice idea, but I am not going to do it.

And I just use that as an example of the difficulty one has in getting the scientific knowledge down into the field to the user.

Dr. LANGENBERG. Mr. Chairman, I spent some time over the last couple of years chairing a committee for the National Academy on the use of information technology in the conduct of research. And I came away convinced, having gone in as something of an amateur, that there is a true revolution going on in the way researchers use, collect, handle, and manage information.

The National Research and Education Network is one aspect of that with which you are more familiar than I.

That revolution, I think, must correspond within the research community to an even larger revolution that is going on outside. It is still in progress; where it will lead, heaven only knows. I am convinced we will find ways to handle the great masses of information.

But I think something that will come from that revolution, that is terribly important, goes back to the diversity and the resilience question. I think a lot more people are going to have a lot more access to a lot more information.

And the way in which we use information in our society for all kinds of purposes is going to change for the better. The guys on the factory floor are going to know things that the boss of the company did not know 20 years ago.

There are some major reasons for hope, it seems to me, somewhere in there. And I think we are all going to be better off for it, when the revolution is complete.

Senator GORE. Well, I certainly agree with that. I have worked hard to get data Superhighways in place and the legislation I now have pending is part of that effort.

I have not consciously focused on that need in this hearing, but I am delighted that at least two of the witnesses have spontaneously brought that up. I think it is our number one priority in science and technology because advanced computers give us the ability to organize and understand and use mountains of data far more efficiently.

And since part of the problem we face in science and technology policy today is this vast surplus of unused and misunderstood data, obviously we can get major gains in productivity by putting more emphasis on the use of advanced computers and the ability to disseminate computer models and visualizations, which make the data comprehensible.

Let me say this, we are running into a time bind, and we have another vote on the floor. What I would like to do, in the next six minutes or seven minutes, is to run through some very fast questions, and then we will have to go to the next panel when we come back after the break.

If this were a TV game show, this would be the lightning round here.

Do all four of you agree that one of our top priorities in science and technology policy is to address the serious deficiencies in science and technology education at the elementary and secondary school level?

Dr. BRANSCOMB. Absolutely.

Dr. COSTELLO. A top priority.

Dr. LANGENBERG. The top I would say.

Dr. ANTHES. Yes.

Dr. BRANSCOMB. Even for me.

Senator GORE. Second, do all of you agree that the infrastructure of science, leaving aside the information superhighways that this subcommittee is pushing hard, that the existing infrastructure of science, laboratories, research facilities, physical plant, et cetera, is in need of priority attention as part of the Nation's science and technology policy?

Dr. LANGENBERG. Yes.

Dr. COSTELLO. Yes.

Dr. BRANSCOMB. Yes. But the intellectual infrastructure is even more important.

Dr. ANTHES. Yes.

Senator GORE. Does that mean the educational system?

Dr. BRANSCOMB. Yes, there are problems the educational system has in addressing the real issues that we face in competitiveness.

And also, back on your information point, the issue really is not whether there is too much information or it is not getting used; people who produce it do, indeed, use it. The problem is we have not given enough attention to the processing of information for others to use.

And I would commend you to look at the National Standard Reference data system, for example, at NST as an example of that.

Dr. COSTELLO. But just to give them new equipment and new facilities, without a new agenda, I think, would be improper. You have got to put the structure of using that data in place so that you know what you are doing.

Senator GORE. Yes. First, the goals, then the software, then the hardware. That is basically what you are saying.

Do all of you agree that the current balance between Federal Government support of defense research versus civilian research ought to be changed with an increased emphasis on non-defense research? Yes or no.

Dr. LANGENBERG. Yes, but—but I will leave the "but" aside.

Dr. ANTHES. Yes, but I would say that I think the remark was made earlier that defense needs to be interpreted more broadly, and that some of the research dollars that are going into more traditional forms of defense should be diverted to other kinds of defense.

Dr. **Costello**. Mine was a yes, but also I think dual use is key. You have a structure in place in defense, where you have a built-in user that can put in place the critical market requirement to institute the implementation in the field.

So I think I want to underscore my position that defense must take a much broader look. It is not just bullets, but it is the whole infrastructure that allows technological leadership, with a good environment.

Dr. **Branscomb**. My "yes, but" is that defense research is very inefficiently used to promote defense's own objectives. And if it were a lot more efficiently used we could, indeed, have more of it for civil purposes.

Secondly, I would observe that on the issue of spinoff, one of the reasons we do not have more spinoff is because we have not resolved a political dilemma: When does a very desirable military-to-commercial spinoff become an unacceptable diversion of public funds for private gain?

When you study firms that do both civil and military work, you will find the firms build huge barriers, deliberately, between these two sectors, so the technology cannot diffuse.

A final point. We relatively poorly understand the underbelly, the infrastructure contribution that defense makes. I think it is much more important than the explicit R&D contracts that they let. The defense procurement, the second effects in small companies, and if we started cutting defense technological activity, not only R&D, but procurement, we want to understand what we lose in the process and be sure to replace it.

I think it could be replaced at lower cost, perhaps, but defense does have a major hidden role that is quite positive.

Dr. **Costello**. I think that we have already put together some efforts like SEMATEC, which provide a basis for an extension of the defense activity looking at the "borderline cases" of industry subsidization. But I think it is important that defense understand it is key to that.

Senator **Gore**. Congress has difficulty comparing big projects to small science when budget time rolls around.

Do any of you have useful, concise advice that has not already been expressed on this subject?

Dr. **Langenberg**. No, just to repeat, that is a priority, Senator, a matter of choosing the correct balance; neither one, nor the other. That ought to be part of the responsibility of OSTP.

Dr. **Costello**. I think it is extremely important that we have a consistent level of support; that we cannot use the R&D efforts as a bill payer, which we often do. We have to say R&D is a bottom line given, and we work from there.

Dr. **Branscomb**. Congress needs to review separately the goal for a big project and the technical strategy for carrying out a big project.

You should demand that once there is a consensus on the goal, let us say for the space station, there is a well thought out technical strategy for achieving the near- or middle-term goals.

And now you want to scrutinize whether the plan is an effective way to do that job technically? If you insist that all big projects go through both hurdles and that that second one is subject to criticism in open debate by technical experts in the community, you will find out that some big projects are better done as many smaller projects. And I will cite the genome as an example.

The problem is we tend to package little projects into big projects because we know that they are politically more attractive when they are packaged that way, at least for somebody who gets the benefit.

Senator GORE. We are going to have a separate hearing on the human genome project a little bit later on. And later today I am introducing Dr. Watson and Paul Berg on that subject. Should the United States continued to offer open access to taxpayer supported research to foreign citizens, or should we place any new limitations on foreign access to U.S. research and education?

Dr. ANTHES. I think to become isolationist in this area would be terrible.

Dr. LANGENBERG. Some barriers for specialized purposes are necessary, but the essence of science is the open exchange of information leading to knowledge, ultimately leading to understanding.

Dr. COSTELLO. We probably should do more to encourage our students to go to the universities offshore as well.

We live in a global economy. We have to have two-way streets, multi-way streets.

Senator GORE. Well, indeed, the openness of science is the key to its success, but with these increased data flows between nations and with the increased importance of basic research to competitiveness, the implication of continued full openness or nearly full openness is that there is an even stronger reason to refine and improve and accelerate our efforts here in the United States to extrude from the basic research useful recipes for improving our competitiveness.

And, in that connection, do all of you agree that we should pay relatively more attention to applied research than we have thus far? You said that?

Dr. BRANSCOMB. No, I think the Federal Government should pay more attention to strategic research than we have so far.

Senator GORE. Strategic research meaning?

Dr. BRANSCOMB. Research in which we have defined the general goal. We understand the general purpose, but we want to pursue it in the way that maximized excellence and inventiveness by the technical community itself.

Applied research is when you hand somebody a problem and you tell him it has got to be done Tuesday. That is not the right role for the Federal Government, except for its own missions, such as defense.

Dr. COSTELLO. I think applying the role of a catalyst for the Federal Government in applying the research is different than applied research.

I think we have to be a catalyst in applying the research, and there is a big role to play there.

I think it depends on how you define applied research.

Any worthwhile project, I think, should have a mixture, a spectrum of research activities ranging from probably the very basic to the more applied, and I do think that in certain areas environmental science we do need more attention to applied research.

Dr. **Langenberg**. Simply supporting more applied research as it is conventionally defined, I think, will not do it. What has to be there are strong incentives to dig into that information base, the knowledge base, and get out there and use it to create something that you can successfully market.

Senator **Gore**. Let me say that other questions will be posed for the record.

We could usefully continue a dialogue here on several other aspects of this larger problem, but I think we have gotten a good start on a general overview of the subject. I want to thank each one of you for helping us get off to a good start in these two days of hearings.

We have a vote on the floor which I hope I make and when we come back, we will start off with the second panel. With that said we will have a brief recess and thank you again.

[Recess.]

Senator **Gore**. Ladies and gentlemen, the subcommittee will come back to order.

For our witnesses and guests let me explain the predicament we are in.

The fiscal year ends in two days, and as a result there have been a sequence of votes on appropriations on the Senate floor.

I went over for what I thought was one vote, and there was a sequence of votes, and we are going to have others.

Normally when circumstances like these come up, we put the statements in the record and put the questions and answers in the record and move on, but as I said to the earlier panel, I am determined that one outgrowth of these hearings be an effort to elevate the significance of science and technology policy.

This subcommittee has to accept that challenge as well, and so I have asked each of the three witnesses on this panel if they would be willing to come back after the lunch break and give us an opportunity to do full justice to what they have to say to us. I know that is an inconvenience to those of you who are here to listen and participate in these hearings, but I honestly believe that that is better than having a perfunctory submission of the statements for the record.

The bells are ringing again, even as I outline this predicament, but each of our three witnesses on the second panel has agreed to come back after lunch, and I think that would be better, really.

Again, I apologize for the inconvenience. It cannot be avoided because of all of these votes on the floor, and so we will reconvene here at 2:00 this afternoon, and we will go from 2:00 to 3:30 or whatever. But that is what I estimate the duration of the hearing this afternoon to be.

I would like to thank our witnesses for their cooperation and that having been said, we will stand adjourned until 2:00 this afternoon.

[Recess.]

Senator **Gore**. The subcommittee will come to order.

Thank you so much for coming back after our unanticipated interruption for votes on the floor. We certainly appreciate your courtesy.

The panel now consists of Dr. Christopher T. Hill, Senior Specialist in Science and Technology Policy with the Congressional Research Service at the Library of Congress, Dr. Joseph Bordogna, Dean of the School of Engineering and Applied Science at the University of Pennsylvania, and Mr. Daniel F. Burton, Jr., Vice President of the Council on Competitiveness here in Washington.

Thank you all for being here and, again, thank you for your courtesy and forbearance in delaying until after lunch.

Dr. Hill, we will begin with you.

STATEMENT OF DR. CHRISTOPHER T. HILL, SENIOR SPECIALIST IN SCIENCE AND TECHNOLOGY POLICY, CONGRESSIONAL RESEARCH SERVICE, LIBRARY OF CONGRESS

Dr. HILL. Thank you, Senator Gore. I do appreciate your determination to continue this afternoon. I think the symbolism of that is important, even if the attendance is lower, and I must agree with you, as one who has spent six years as senior specialist in science and technology policy, that you would like to make those issues more important in the Congress. That certainly is personally appealing.

I would like to do two things. I would like to describe some of the major changes in trends in science policy during the 1980s, which was a period of major shift in a lot of our perceptions, and then I would like to identify some of the major challenges facing us for the 1990s.

There is, of course, a great deal of convergence already between what I will say and what was said this morning, and that will allow me to move pretty quickly through some of this and summarize it.

First, I would like to venture an assumption. Francis Fukuyama has gotten a lot of attention recently for saying we may be at the end of history, but I think whether we are there or not, it is clear that we are not at the end of science, that science has only begun, and that we have only begun to experience its benefits.

Our challenge is to learn how to make science and technology happen in a way that we want to so that we can take advantage of its fruits while controlling the waste that it inevitably brings us as well.

Let me turn to some of the changes that I see in science and in science and technology policy. The first is that science and technology now matter. They make a difference. In particular, they are perceived to matter to the economy, and that is relatively new in the last decade.

We recognize the importance of science and technology in national security and public health matters, but it took almost 40 years for the other lesson of Vannevar Bush's book, Science: The Endless Frontier, to sink in: that science and technology are important to the economy.

Two major events spurred this understanding. One was the domestic policy review on industrial innovation carried out during the latter part of the Carter administration, which led in part to the passage of the Stevenson-Wydler Technology Innovation Act of 1980, which originated in this subcommittee.

Now, since then, there have been a number of other pieces of legislation which I outline in my detailed testimony that have been intended to encourage technological change for economic objectives.

The second change is that we have reduced the barriers among the various performers of R&D and between the performers of R&D and the users. It is hard to overestimate the degree of estrangement that existed, say, around 1980 between performers of research in universities and industry and between the folks in the industrial research laboratories and the folks in the factories who had to make use of the fruits of that work.

And we have been very fortunate in the last decade to find ways to break those barriers down with some changes in federal patent law, with the Federal Technology Transfer Act, with university-industry cooperative research centers, and with engineering research centers and all the rest.

The third change is that there has been a real change in our understanding of the processes by which R&D and science and technology contribute to social and economic advance. This has been talked about this morning. I will not belabor the point, but we no longer believe that science—that breakthroughs in science—leads directly to new gadgets and new products which engineers then perfect, commercialize, and bring to the marketplace.

We know that the process is both more subtle and more complex than that. Instead, I find it useful to talk about what goes on in terms of the theory of continuous incremental improvement.

Most important new technologies are simple refinements of old technologies. A 1990 Ford is nothing but a 1936 Ford with a lot of improvements added to it over time, and much of Japan's success in high technology manufacturing can be attributed to its ability to take advantage of that process.

The challenge for us and for policymakers in the Congress and the administration is to decide how to interface with this new understanding of how the industrial R&D process occurs.

The next advance I want to mention—the next change—is that there has been a tremendous increase in the price that it takes to do a fundamental piece of science.

As we have pushed the frontiers of science forward and have tried to measure things that go faster or weigh less or are at higher temperatures or are smaller, the cost of the instruments has gone up astronomically.

I can tell you how much heat is given off by a kitchen match with some equipment that might cost $100 to assemble on a lab top but if I want to know how much energy is given off when two 40-trillion electron volt protons hit each other, I have to spend $6 billion on a supercollider, and that is the kind of science we are trying to do today.

I do not have to say anything more than to tell you that interest and achievement in math and science and engineering have declined, despite the fact that we now define our society as a society of technology.

This is an era of technology, and we are rapidly becoming unable to cope with it.

If you are following the numbering in my written testimony, you will notice I left out point 6. That lets me insert one, and that is the growing importance of the states in science and technology. I just want to comment here on the question posed this morning about the federal role in trying to coordinate states' science and technology efforts.

I am not quite so sanguine as some of this morning's witnesses were. It does seem to me that there is a problem at the state level with the independent state programs, and that is due to what I would call the bandwagon effect.

Someone told me recently that there are over 80 separate and distinct state and local biotechnology initiatives in the United States. I am not sure we need 80 biotechnology initiatives. Maybe we ought to have 77 biotechnology initiatives and three more initiatives in near net shape forming.

It is hard to get a state legislature very excited about near net shape forming whereas, they may think they understand biotechnology or robotics or advanced materials. But I believe there is some role, not for federal control, but for some federal feedback on how are we doing.

Maybe we have too many people playing too few tunes, and paradoxically we will get more variety in the system with a little stronger conductor who can tell the French horns now is your time; you do not have to play the same note that the violins are playing.

Another change that is terribly important is that our ability as a nation to design, assess, implement and evaluate new public and private initiatives in science and technology has not kept pace with the challenge. For example, we know there is a backlog of outmoded scientific instructional and research equipment in the high schools and the colleges and universities. A number of our major industrial laboratories have closed over the last decade. We have changed the character of Bell Labs. Exxon closed a major lab. The RCA labs have changed entirely in character. A big energy laboratory in Pittsburgh has been shut down.

We could go on down the list. We have very few technically trained professionals who can read and write and interpret Japanese literature. It has been ten months since President Bush was elected, but there are still all sorts of unfilled positions at OSTP, the Department of Commerce, and the Department of Energy, and the administration's promised action plan on high-definition television may never show up. We just do not seem to be able to get on with the game in a lot of places.

Let me turn for a few minutes, then, to the business of the future.

First, we have more scientific opportunities than we can afford. We spend over $60 billion a year of public money on research and development in industry and others spend $70 billion more, and most scientists would like to spend billions more than that. Because of the pressures on the federal budget and because of the higher priority we attach to other national needs, the federal R&D budget on the civilian side has hardly grown during the last decade, and military R&D spending, which did grow very rapidly in the early eighties is, in fact, on the decline at the current time.

But, at the same time, the scientific community continues to propose, and both President Reagan and President Bush have endorsed, major new scientific and technical projects while continuing to say that we must support the base of small projects at NSF, NIH, and so on.

To pay for these new opportunities in science, it seems to me we must look at the options. We either have to be willing to divert funds from other deserving areas, accept greater budget deficits, or raise taxes.

The current temporizing on funding for big civilian R&D projects is strongly reminiscent of the "bow wave" of early stage funding for new weapons systems. Eventually all the new starts come back to haunt you, and you have to make some hard decisions about what to cut or how to pay for the things that looked so nice when you were in the early stages.

Well, there is a lot that could be said about meeting our educational needs for the future. Let me just mention two. First, one of our colleagues talked about pre-college math and science. I think we need to stop doing that. We need to talk about K-12 or elementary-secondary school math and science, because half of our people do not plan to be "pre-college." They never are going to go to college.

But it is essential that they understand about math and science. When we talk about the need to revitalize pre-college math and science, we are telling half the kids in the country, "this is not for you," and I think that is bad.

Second, in order to reverse the decline in the numbers of Americans who go on for doctoral degrees in math, science, and engineering, we might want to take a hard look at how we support them financially.

Over the last decade or so, or decade and a half, we have shifted our mode of support to research assistantships on grants that faculty members receive and away from fellowships. The effect of this shift is to create great uncertainty in the mind of the young person who is thinking about going to graduate school, but who does not know until he gets there whether there might be financial aid, while on the other hand he is looking at a certain $32,000 per year job offer from a major company.

If we shifted some NSF, NASA and other money out of faculty grants and into fellowships, we would not have to raise the budget, but we might be able to bias the system in favor of American citizens and encourage more of them to go ahead.

We have another challenge: to make creative use of conflicts of interest. We have to take a hard look at whether, in trying to root out conflicts of interest, which are so concerning us today, we may be shutting off some of the venues of communication and interaction that can be used to build consensus in our society, and whether that is leading us to lose senior people at NASA and DOE and DOD and making it hard to hire new folks.

We need to learn how to make public policy when science is not conclusive. You know, in the Science Policy Research Division at CRS we get several thousand questions a year from Congress, and almost none of them have to do with facts.

Where there are facts——

Senator GORE. What do you mean by that?

I am just kidding, go ahead.

Dr. HILL. Where there is incontrovertible agreement on the facts, you and your staff do not have any problem. It is where two or more sets of facts can be marshaled to argue in favor of two or more conflicting public policy options that we have trouble, and where we look to science for answers. But, for most of the important questions that come to the public arena, science cannot provide definite answers. Global warming, as you well know, is one of those cases in which you can marshal scientific facts on several different sides of issues like what happens with fluorocarbons in the atmosphere.

We still have a lot to learn, I believe, about the psychology, the science, the economics, and the law of making decisions when science will not give us the answers, as Leu Branscomb also alluded to this morning.

Finally, our most important challenge may be to build a decision-making process that is adequate to the challenge of the global technological world we live in.

There have been a number of suggestions for strengthening our ability to make these choices, ranging from increasing the technological capability in the Department of Commerce, to revitalizing OSTP, to creating a department of science and technology, but these organizational changes may only be part of the answer.

Perhaps it is even more critical to put some human and other resources into some of the urgent tasks that we face and to change some of our outmoded habits of mind regarding what it is appropriate for the federal government to do.

Finally, since no one seems to know what the optimum technology policy for the next decade should be, perhaps we ought to do some experiments. Perhaps we ought not try to agree on everything in advance, but find some plausible things to try, and move away from the interminable theoretical debates that have us hung up on whether we should or should not do something. Perhaps we should go ahead and try a few things and see if we can learn a little bit more about what the limits of the ability of this nation are. Thank you.

[The statement follows:]

STATEMENT OF CHRISTOPHER HILL, SENIOR SPECIALIST, SCIENCE AND TECHNOLOGY POLICY, CONGRESSIONAL RESEARCH SERVICE, LIBRARY OF CONGRESS

Mr. Chairman and Members of the Committee. My name is Christopher Hill. I have served for the past six years as senior specialist in science and technology policy at the Congressional Research Service. It is my pleasure to respond to your request for testimony from CRS regarding "...today's main issues and choices in the field of science and technology policy."

In my testimony today, I would like to do two main things:

1. Describe some of the major changes and trends in American science and technology policy during the decade of the 1980s, and
2. Identify some of the major challenges facing Congress and the Nation in maintaining, renewing, and establishing new science and technology policies for the 1990s.

In keeping with the CRS precepts of objectivity, non-bias, and non-partisanship, I will refrain from expressing personal views or preferences as to the desirability of alternative courses of action open to Congress. However, I can provide information and analyses of the potential consequences, costs, and benefits of different choices where I am competent to do so. Since national science and technology policy for the 1990s encompasses far more issues than can possibly be addressed in a few minutes or pages, I will have to be selective.

The world may or may not have reached the "end of history" as suggested by Francis Fukuyama, but we have surely only begun to experience the beginning of scientific and technical advance. There is much more to come, and the grandest challenge of all is to learn how to make it happen, and to take advantage of its fruits while controlling its wastes.

CHANGES DURING THE 1980s

1. Science and technology now "matter".

There has been a marked increase in the degree of awareness among public officials and the public at large that science and technology are important to the Nation's well being. Certainly this has been accepted at least since World War II with respect to applications of science and technology to national security and to the health of the Nation's people. What has increased dramatically is the awareness that science and technology matter to the economic prosperity of the country as well, underpinning such important economic factors as productivity increase, the balance of trade, and economic growth.

Two watershed events mark the beginning of this trend: the Domestic Policy Review on Industrial Innovation carried out by the Carter Administration in 1978 through 1980, and the passage of the Stevenson-Wydler Technology Innovation Act, originated by this Committee, also in 1980. These events were followed by several other legislative actions during the ensuing decade intended to encourage technological change for economic objectives, such as the Small Business Innovation Development Act of 1982, the National Cooperative Research Act of 1984, the Federal Technology Transfer Act of 1986, the Technology Competitiveness Act (within the

Omnibus Trade and Competitiveness Act of 1988), and the Technology Administration Act of 1988. In a historical sense, these and related Acts of Congress and actions taken by the Administration can be seen as completing the broad outlines for a three-part national science and technology policy focusing on military, health, and economic-related research laid down in the famous Bush Report, Science: The Endless Frontier, in 1945.

2. Barriers among the R&D performing and using sectors have been lowered.

For much of the post-war period, but especially during the 1960s and 1970s, rather formidable barriers to communication and cooperation grew to separate performers of R&D in universities from those in industry, and to separate the performers of R&D in industry from those in manufacturing who are the ultimate users of its results. The reasons -- intellectual, political, and financial -- for these estrangements are too extensive to explore in depth here, but the Nation is fortunate that over the last decade ways have been found to build new bridges among the various entities, or even to break down some of the distinctions altogether, with a resulting re-energizing of the research and technology development systems of each sector: industry, universities, and government laboratories. Important to these developments were such activities as the Industry/University Cooperative Research Centers, Engineering Research Centers, and Science and Technology Centers Programs of the National Science Foundation; as well as passage of several pieces of legislation facilitating access to, and rewarding exploitation of, scientific and technical advances made in universities and government laboratories under government contracts or by government employees.

3. Understanding of the processes by which research and scientific advance contribute to technology development and economic growth has matured.

At the beginning of the 1980s, and indeed well into this decade, it was widely believed that scientific advance contributed to technological development in a straightforward linear way; that scientists doing research discovered new phenomena which engineers doing development subsequently transformed into saleable products through a somewhat mysterious process called "commercialization." In its simplest formulation, it was said that basic research led to applied research, which led to development, and thence to commercialization and to manufacturing. While this model is adequate to describe reality in certain highly visible and important instances (nuclear power and exploitation of genetic manipulation techniques, for example), it has been rapidly supplanted during this decade, and especially during the last year and a half, by a more subtle and complex model: the model of "continuous incremental improvement." According to this model, which is now widely embraced in industry and by many in government and the universities who think about such matters, most economically significant new technologies are based on marginal improvements to existing technologies. The new 1990 automobiles, for example, are in some profound sense simply the result of the continuous upgrading of the new models for 1936 or 1924. Many observers have attributed much of Japan's success in important high-technology products to its mastery of this approach. It has come to be realized, then, that the main challenge for industrial R&D managers is to ensure that such continual change occurs rapidly and effectively, rather than to search for a stream of revolutionary breakthroughs. The latter are welcome when they come, but they are no longer seen as the bread and butter of the R&D game.

4. The next advance in many areas of fundamental science has become enormously expensive.

As our ability to record and measure phenomena has been extended into realms of mass, length, time, temperature and energy that are ever more distant from ordinary human experience, the complexity and cost of the instruments necessary to make such observations have tended to grow accordingly. For example, to measure the length of an object that is as long as your arm; a yardstick that costs a dollar may do; to measure the diameter of a fine wire may require a micrometer that costs $10; while to measure an object the size of an atom may require a scanning tunneling microscope costing hundreds of thousands of dollars. And, while one can measure the energy given off by burning an ordinary match using simple laboratory equipment costing perhaps a hundred dollars, to create and measure particles having energies of the order of 40 trillion electron volts may require a $6 billion superconducting super collider (SSC). An inquiry done a few years ago found that the SSC would be more expensive in real dollar terms, by a factor of three or more, than any other scientific instrument ever constructed.

6. Interest and achievement in mathematics, science, and engineering by American students and citizens have declined.

These declines, which have been widely documented and discussed, began perhaps as long ago as the mid-to-late 1960s, but they have emerged with a vengeance in the 1980s. There are some bright spots, like the increasing numbers of women who complete college degrees in science and engineering, the moderate upticks in scholastic aptitude test scores in recent years, and the bulge in engineering enrollments in the early 1980s (now largely over). However, most measures suggest that the scientific and technical competence of the American people -- at all levels -- has declined, even as the importance of such knowledge to our Nation's future has been more widely recognized and as advanced technologies have become ever more prevalent in daily life.

7. The Nation's capabilities to design, assess, implement, and evaluate new public and private initiatives in science and technology; that is, the "infrastructure" for science and technology, has not kept pace with the demands placed on it.

Numerous indicators point to erosion in the Nation's scientific and technical infrastructure, not only in the physical plant and equipment, but in the deeper capability of the Nation's private and public institutions to act constructively and effectively once a need or an opportunity has been identified. These include such disparate indicators as the backlog of outmoded scientific instructional equipment needing to be replaced in our secondary schools; the disappearance of several major industrial laboratories during the last decade; the shortage of technically-trained professionals who can read and write Japanese; the fact that over ten months after the 1988 Presidential election, the four Associate Directors of the Office of Science and Technology

Policy have not yet been nominated, the Undersecretary of Commerce for Technology has not been identified, and fourteen of eighteen top appointive posts in the Department of Energy remain unfilled; and the fact that the Administration's action plan on High Definition Television promised for early July has not yet, and may never, materialize. The budget deficit is at the root of much of this delay and indecisiveness in the public sector, but so is the lack of a national consensus that some of the contemplated actions should be taken. Another reason is the increasing burden put on the system by ethics and conflict-of-interest rules and concerns.

CHALLENGES FOR THE 1990s

The major changes in science and technology circumstances and policies during the 1980s that are listed above, along with many other problems and changes too numerous to mention here, pose challenges to the Congress and the Nation in maintaining, renewing, and establishing new science and technology policies for the next decade. Congress may wish to respond to these and other challenges in science and technology by, for example, redirecting funding among agencies, programs, and projects; establishing new or eliminating old activities; or reorganizing some or all of the Federal agencies that support or influence scientific and technical activities. In so doing, the targets of such policy changes might include not only the Federal agencies themselves, but also the major performers of R&D in the Nation (industry, government, universities, and independent laboratories). The following are among some of the more critical of these challenges.

1. We have more scientific opportunities than we can afford.

The Federal Government currently spends over $60 billion per year on R&D, and industry and other sources spend nearly $70 billion more. Despite these very large outlays on R&D, many if not most scientists and engineers believe that much more could be profitably spent. Nevertheless, because of the pressures on the Federal budget and the higher priority attached to other national needs, the Federal R&D budget on the civilian side has grown only marginally over the last decade, and military R&D spending, which grew rapidly in the early 1980s, has actually declined in real terms in recent years. At the same time, the scientific community has proposed, and both President Reagan and President Bush have endorsed, spending large amounts of funds on major new scientific and technical projects while also implicitly endorsing continued growth in the base of smaller scale projects. At the extreme in expense, the President recently endorsed a manned mission to Mars, whose cost has been estimated at $400 billion. Without taking account of such niceties as inflation, cost-sharing with the Soviet Union, and the actual pace of expenditures, if such a project were to be carried out over 20 years, it would cost an average of $20 billion per year, which is essentially equivalent to the total annual Federal spending on non-defense R&D. Put another way, this one very large project might require a doubling of the Government's spending on civilian R&D, unless deep cuts were made in other areas such as energy and health R&D.

Some in the scientific and technical community have embraced the notion that explicit priorities should be set among competing R&D projects -- with their advice and consultation, while others continue to argue that "new money" should be found to support them. To illustrate, I recently had the opportunity to pose two questions to a group of senior R&D executives from all four sectors: (1) which R&D projects would you suggest be cut in order to find funds for new starts, and (2) would you be willing to pay higher taxes in order to pay for increased national investments in such areas as R&D, education, and physical infrastructure. Of the 130-odd persons in attendance, a clear majority was unwilling even to take these questions seriously, let alone attempt to answer them.

With respect to paying for the new opportunities in science, then, it seems clear that the options are to divert funds from other deserving areas, increase revenues, or accept greater budget deficits. Otherwise, it is difficult to see how such large new projects as the Mars mission, space station, superconducting super collider, or doubling of the budgets of NSF or NIST can be reasonably carried to completion. The current round of temporizing on funding for big civilian R&D projects is strongly reminiscent of the "bow wave" phenomenon widely discussed in connection with the early stages of funding for new weapons systems; eventually hard choices will have to be made.

2. Meeting educational needs for the future.

There seems to be nearly universal agreement that reform and revitalization of the Nation's educational system is essential, as the Office of Technology Assessment put it, "From Grade School to Grad School." Let me mention just two areas of concern among the many that clamor for attention.

First, it seems to me that we need to avoid talking about "pre-college math and science" education, for the simple reason that a significant proportion of our population has no plans to go to college, but still needs to be reasonably literate in math and science to contribute to our economy and to function in our technological society. To avoid inadvertently signaling that math and science are not for them, we need to change our rhetoric to talk about "K-12" or "elementary and secondary school" math and science so as to include everyone.

Second, it is well known that there has been a decline in the numbers of Americans who go on to doctoral degrees in math, science, and engineering, as well as a sharp increase in the number of foreign students in those same fields. One possible approach to reversing this trend might be to change the way in which Federal agencies support graduate research and education by moving away from indirect support of graduate students through faculty research grants and toward direct support via fellowships and traineeships, which were more heavily used in prior years. This would both give prospective students greater assurance of financial assistance before they commit to going to graduate school, and tend to bias the support more toward citizens and away from non-permanent aliens. It would also not cost any more than the present approach.

3. Making creative use of "conflicts of interest".

At present, America seems bent on discovering and preventing conflicts of interest in nearly every corner of life. Yet, I am struck by the fact that many of the institutional arrangements in Japan, for example, to which we attribute their recent success in the international marketplace would be characterized as fraught with conflicts of interest by U.S. standards. To illustrate, it is well known that in Japan there are close relationships between the bureaucrats in the government agencies and the leaders of private companies and banks. It is said that these relationships facilitate arriving at shared understandings of national technology strategy and that they lead to rapid and efficient transfer of information about technology, markets, policies, and such other matters as environmental standards among all parties. Japan has a tier of high-level positions in the various sectors designed to be filled by alumni of the others. At the same time, we are trying to expose and impose further controls on such activity. Recognizing that Japan is not the United States, and that there are good reasons to control conflicts of interest in our large, pluralistic country, nevertheless such matters as the current difficulties that Federal agencies are having in attracting and retaining senior technical staff due to concerns for actual or potential conflicts of interest suggest that we may need to give this area a fresh look.

4. Adapting science and technology policies to a world of continuously improving, global technology.

Existing science and technology policy, especially that motivated by concerns for general economic and social development, is predicated on two premises: (1) that the U.S. Government can influence domestic technology development and applications essentially independent of what happens in other nations, and (2) that basic research in the sciences leads more or less directly to the development and use of new technology. Neither premise is adequate to the new circumstances, and policies based thereon seem inadequate or perhaps even counterproductive. For example it is generally understood that Federal support for basic research is important to U.S. industrial technology, and that it works best when the results are published openly and disseminated widely. Yet, some are asking whether Federal support of basic research in universities (the major way in which we have implemented the third leg of Bush's 1945 proposal) is a sufficient strategy to ensure that American industry stays a leader in world technology, and others are asking whether new limitations should be placed on communication of scientific and technical results to inhibit their falling into the hands of competitors.

On the other hand, others have begun to express concern that the universities, which have been asked to redirect a good proportion of their natural science and engineering research more toward serving industrial needs, may be facing destructive pressures to move away from the unfettered search for new knowledge that might underlie the next scientific revolution. And, others are pointing out that attempts to limit the flow of American technical information overseas may work to our long run detriment by undercutting one of our remaining advantages in international economic competition, the free exchange of scientific and technical information between researchers and users.

5. Learning how to make public policy when science isn't conclusive.

Science and technology policy is not only about how to direct resources toward the further advance of such understanding; it is also about how to make the best use of scientific and technical information, which is often incomplete and uncertain, in making public policy decisions in a host of other arenas, from pharmaceutical regulation to defense strategy. Science in policy is as important as policy for science. The relatively easy cases are those in which science and/or technology provides a reasonably certain and conclusive piece of information to policy makers; as, for example, when a scientist points out that "time travel" is impossible according to everything we now know to be true about physics. But, there are few cases of this type. Much more common is the case in which scientific evidence and understanding can be brought to bear to support two or more incompatible policy choices. Despite strenuous efforts during the last two decades to learn better how to employ uncertain scientific and technical information in such decisions, both the science and the psychology, as well as the economics and the law, of such matters are insufficiently well-developed and need more attention.

6. Learning from prior policies about how to do better next time.

We at CRS are major consumers of the kinds of studies and analyses that are intended to ferret out intelligence about how well public policies in the field of science and technology are working, or not working, in accomplishing the goals set out for them by Congress and various administrations. Such work provides some of the raw material for our reports to Congress on diverse topics, especially in carrying out our mandate to help Congress anticipate the consequences of policy choices. During the last decade, intellectual progress on this sort of evaluative research and analysis has slowed down in the United States, even as several European countries and Japan have vastly increased both their capabilities to conduct such studies and the importance attached to them in policy making. During the 1960s and 70s, more Federal resources were devoted to these kinds of studies than seem to be available today, especially from the agencies that have the support or encouragement of R&D as one of their missions. Congress may wish to urge agencies to restore greater attention to such matters, following upon one of the adages attributed to the quality control expert, W. Edwards Deming, "Anything you measure gets better."

7. Building a decision making process adequate to the challenge of a global technological world.

As noted above, the "infrastructure" in the United States for addressing major scientific and technological issues is not as robust as it might be, in view of all the challenges that need to be addressed. Numerous ideas have been advanced for dealing with this problem, ranging from this Committee's efforts to strengthen the technological capabilities of the Department of Commerce, to the revitalization of the Office of Science and Technology Policy now apparently underway in the Bush Administration, to the proposed creation of a new Department of Science and Technology. At this point, each of these approaches and others has its adherents and its detractors. However, it may also be that organizational changes are only a part of the solution, and that what is perhaps even more critical is a genuine determination to devote the human and other resources that are needed to these urgent tasks, to overcome outmoded analyses and habits of mind regarding such matters as the proper distribution of effort between each of the separate parties in the national R&D system, and to adopt a spirit of genuine experimentation with public policy that accepts that none of us really has "the answer" regarding the optimum science and technology policy for the next decade and that we must take risks in order to learn.

Senator GORE. Thank you very much.

Our second witness will be Dr. Joseph Bordogna. Please proceed, Dr. Bordogna.

And we may have to interrupt you halfway through your testimony, again, for the vote. But, please, go ahead.

STATEMENT OF JOSEPH BORDOGNA, DEAN, SCHOOL OF ENGINEERING AND APPLIED SCIENCE, UNIVERSITY OF PENNSYLVANIA

Dr. BORDOGNA. I would like to begin by commenting on the interchange this morning with the panel; it forms a good base for some of the things I want to say.

There was a discussion, a very in-depth comment about thinking differently these days than before. Most creative work was done based upon things you could see and touch in the old days. There was mass to it. Most of the things that we deal with today are designed from things we do not see, the microscopic. So it sets a different kind of scene.

Another comment had to do with the mountains of data being generated today and how to handle it all. There are two aspects to this. One is if we do have the network and we do have fiber optics skirting the Earth, more people are going to access the data, not just those who are "supposed" to access it. With more people accessing more data, it is going to be very difficult to handle the data without having some intelligence built into the system. There are ways to approach this need, ways that reflect how we are approaching engineering education right now.

Finally, there was a comment by Dr. Langenberg who talked about having a strategy for national policy with the Federal Government as coordinator. I would comment that I think there is a corresponding national strategy for engineering education to develop. I think there is consensus about it, we are moving on it, and there are some good things happening. For example, we all know about the numbers. We know that enrollments are decreasing; engineering enrollment decreased another 10,000 from 1987 to 1988. (We do not have the 1989 data yet, because the school just started.) But it is interesting to note that in the 10,000 drop in overall enrollment during the past year, there was a 1,500 student increase in the minorities area. Also, enrollment of women is going back up a little bit. We do not quite know why that is happening. It might be a demographic glitch. But there is some movement that way.

There have been a lot of studies, somebody mentioned this morning all the studies being made. In the engineering profession, we are to the point where we think the studies are done. There is some action underway and we think we know the way to go. We have developed a strategy.

Part of the strategy has to do with defining what the modern engineer should be. It has a lot to do with the goal of academe for 900 years, since the first university was established in the Western world, to educate with everybody in "breaking things apart."

Education at the highest levels deals with fractionization of knowledge. You keep breaking it apart, getting down deeper into its substance. Nobel prizes are garnered that way, and our nation does pretty well on that.

We have gotten very poor in putting things together. We need more "integrators" of knowledge. We have to have engineers go out there and take everything that is extant, the ideas, the systems, the new technologies, and put things together. We have not done this well; we intend to.

We feel there are four major facets to a modern engineer's education. And again, one should know there is much consensus about this in the major reports written during the past few years. One is the idea of integrative capability. It is very, very important. We feel engineering should be defined as an integrative process; construction of the whole, if you will, rather than an analytical breaking down. Engineers have to be proficient analytically, but they also have to be able to put things together, to build. Integrative capability is the recognition of engineering as an integrative process, in which analysis and synthesis is supported with sensitivity to societal need and environmental fragility.

Analysis capability deals with critical thinking, which underlies problem definition. We have decided that engineers defined as problem solvers is necessary but not sufficient. They have to *define* the problem, ask the right questions and set it up better. We want to teach them to do that well.

Innovation and synthesis capability relates to the creation and elegant implementation of useful systems and products, including their design and manufacture. And I want to say something about manufacturing here because a question in the letter you sent to me asked for comments about manufacturing problems in the country. We are having an argument about this in the engineering profession. Manufacturing is not just making better robotic factories. We think manufacturing productivity and efficiency has a lot more to do with taking the data available for creative work and applying them some way in intelligent systems for the production of new products. We feel that is a higher order thing and that it is the thing that will carry us past competitors internationally.

And finally, conceptual understanding. Our engineering graduates have to place things in context; they have to appreciate the economic, industrial and international environment in which engineering is practiced, and the ability to provide societal leadership effectively. They have to be involved.

Now with those definitions, over the last two years, recent NSF reports have suggested we do some of the following. I will just mention a few of them from my written testimony.

There is a fundamental one. Usually we take our engineering students, when they graduate from high school, where they have experienced fractionated knowledge (physics, chemistry, mathematics, English, etc.) and nobody has put the pieces together in some sort of story for them, we take them into the freshmen year, they are all excited about doing engineering, and we then send them off to the hinterlands to study the same subjects they studied in high school.

Thus, a major thrust now, and NSF wants to support this, is to flip that around a bit. When the students come in, let them do their engineering; learn it well. And we have a cute little term (invented by Professor Van Valkenburg) called just-in-time education, like just-in-time inventory. If you look at what engineers really do in life, they get a problem, it is open ended, and all the answers are not known, but, you have to get it done. So you go out and learn what you do not know in order to do it. The idea here is get the students started early on the engineering process and then help them garner information as needed to complete the "project", just in time.

We really do need to do something about the laboratories. And it is not the question of just the infrastructure deteriorating physically; it has more to do with building laboratories that really work better—a more intellectual approach to that.

We also need to stress foreign cultures and languages. (Everybody is having a big argument about requiring language for engineers.) And we need more focus on attracting women and minorities to engineering. There are programs to do this and we would like for everybody to really support them.

Now, that is engineering education. There is a pipeline to all of this, and this morning everybody answered your first question by saying the top most important thing is K through 12 education. I think everybody agrees with that. But even if we do a good job there, so that the students are more literate and well prepared and more qualified, and the pool of people qualified to take engineering is larger, they still may not come. There is a motivational aspect needed as well.

I want to describe to you two programs in this context, which I was asked to describe, PRIME and PRISM. And I want to describe them in a way that shows there is a continuum of modern education from K to Ph.D. A lot of us have begun to feel that, in a regional area, for example like the greater Philadelphia-Camden region of the country, where there are millions of people and hundreds of thousands of students, we should band together and attack the problems together, that is, industry and universities really digging in with their colleagues in the school system to do something meaningful. PRIME and PRISM were formed to this end

PRIME is a minority program to motivate students to engineering. It started in 1973. It is a Philadelphia area consortium of universities, industries, the School Districts of Camden and Philadelphia, community groups, parents, and so on. The key to it is people on the PRIME Board of Directors at very high levels. When the Board makes a decision, they do not have to go back to their companies and schools to check it out.

Since 1973, there have been 40,000 minority students go through PRIME. There have been about 29,000 go on to college, and the retention rate for those people is 85 percent graduating.

Senator GORE. Let me ask you to pause there. We are in the final stages of a vote on the floor, actually, that affects federal spending for research and development. I anticipate it will only take about 10 minutes, so we will recess for 10 minutes and then resume.

[Recess.]

Senator GORE. The subcommittee will come back to order.

Again, my apologies for the interruption.

Dr. Bordogna, you were in the middle of your statement. Please, proceed.

Dr. **Bordogna**. Let me just say a few sentences to get us back in order. What I am trying to do here is show that there is a continuum between kindergarten to Ph.D.

In engineering education, what we want to do is enhance. And we are beginning to do it, to change the sense of the students to be able to go out and integrate more and build things, more than just being analytical and understanding what they do.

How do we feed students into engineering? Well, we have kindergarten through 12th grade and we have to both motivate the students as well as educate them that science and engineering are important.

And I was in the process of describing two supportive programs. One is PRIME, which is a minorities program started in 1973. And the important thing about it is a consortium of everybody in the community.

While you were out somebody was asking me where does the money come from for that? It has come from everybody. Industry has put an awful lot of money in. You will see, sprinkled through my written testimony, purposely, the names of companies who have invested money to this end.

The Federal Government has also given some money; it has been seed money until recently. Also, there have been projects for which the School District of Philadelphia has put line items in their budget to do things derived from PRIME projects.

PRIME has been very successful. It identifies students in the 6th and 7th grades and it takes them and tracks them through to 12th grade, with a lot of support, both intellectual and career kind of support.

We have academic year programs for them in the schools, middle schools and senior high schools in Camden and Philadelphia—a great many high schools.

There have been 40,000 kids going through; 29,000 have been through the program who have gone to college; and we have 85 percent retention of those in college.

This past year, the PRIME "graduating class" from all the high schools in the area amounted to about 200, and 99 percent went to college. The only person who did not go—there was one who did not go—he went into the military service, and 92 percent went into science and engineering programs.

We have 3,000 students in the program every year.

And there is a summer program, starting after the 8th grade, in which the students go to one of four campuses, Drexel, Penn, Temple and Villanova, and spend a month there. And the Villanova experience is at the end, between 11th and 12th grades, and they actually live on campus.

So if you can imagine inner-city kids in a whole new world they have never seen, where they can get some pride and good feeling. There is a lot to that, besides all the rigor we give them in math education, English, and computers, and it is pounded all the time, but it is done in a way to motivate them to a life they may want to go to.

And the numbers are very large.

Now the PRIME program is student-oriented. It has been around a long time. And one of the dreams we had back when we started this in the early 1970s was the thought that we ought to spread our efforts to all the kids, not just the ones we identify as having better ability. We felt that the things we were doing really were useful for the whole school system.

Another idea was to help start something to train teachers, upgrade them, and also give them some dignity. One of the problems with the pre-college teaching environment is the teachers really have lost some dignity, because they are not really included as distinguished members of the community.

So we asked the teachers in. We even have the head of the teachers' union in Philadelphia involved with us all these years, so that we can make sure things are done on a very, very collective level.

In 1985, we thus created PRISM, Philadelphia Renaissance In Science and Math. There is a corollary part called PATHS, Philadelphia Alliance for Teaching Humanities in the Schools. These two cultures are combined in an organization called the Philadelphia Partnership for Education. The student-based PRIME is now part of PRISM/PATHS. PRISM/PATHS is aimed primarily at teacher support. My written testimony details a whole list of things that are going on in PRISM. I just want to relate a few that are very, very exciting.

One problem is this myth that elementary school teachers do not like science; that is, they never had it in college and thus they do not teach science to the kids.

We have a program in Philadelphia under PRISM that is educating all elementary school teachers—some 400 so far—with science kits developed with some money from NSF and a few charitable trusts and foundations. The science kit is very easy to use, and we are training the teachers on it. And now there are 54,000 elementary school students in Philadelphia being educated in the 1st to 6th grades with these science kits.

Another exciting part of this is we have sort of a mini National Science Foundation research program in PRISM. This is a program which funds, at $150,000 a year, projects that teachers, collectively or singularly, submit to a group of us for research projects that they want to do. And we actually fund teachers from 1st grade to 12th grade with ideas at up to $3,000 on a project. This past year we received over a couple hundred proposals and funded 144; it is a very, very exciting kind of thing.

There is a project to enrich teachers by getting them out into industry. The idea is to invite teachers, particularly in science and math to summer jobs doing real engineering and science work with industrial firms.

Lately, we have had some very exciting bigger projects. PRISM has a $3M+ NSF-funded grant for a comprehensive regional center for minorities. These are new national programs, and ours, again, is run by our regional consortium.

The idea here is to really start to pull together all the activities from kindergarten to Ph.D., in the sense of the teachers being trained, the kids better education, the teachers developing dignity and becoming more professionally oriented, the students going off to college with good preparation and being retained, some through the Ph.D., so we get some role models out at the other end.

Dr. Langenberg, who was here this morning from AAAS, described AAAs project 2061. PRISM is working with AAAS, as one, I think, of six school districts across the country, in trying to develop a new kindergarten through 12th grade science curriculum.

Just as a few results of these PRIME/PRISM things, the proportion of high school students in grades 10 to 12 enrolled in higher level science courses in this region of the country has increased by 20 percent since 1984; and the proportion enrolled in higher mathematics courses has increased by 30 percent.

The massive, five-year, $5 million program to provide science kit materials and training for 6,000 elementary school teachers has been underway for several years. With the result so far of the elementary school teachers we have trained, using these kits, in those particular classes, students have scored 16 percent higher than other students on curriculum-referenced tests.

So there are a lot of positive results from all of this.

Finally, I want to say something about master's and Ph.D. programs. One of the problems that we face in engineering education is that in the big research universities, where we pump out the Ph.Ds., the graduate students and the faculty are working very hard at fractionating knowledge. They write dissertations on very focused things. And that filters down to the master's program. The master's program becomes a stepping stone to the Ph.D., and preparation for it, and it filters down to teaching and the baccalaureate.

Now we have to work very hard now, and what we are thinking of doing is fractionating or bifurcating at the baccalaureate level two routes.

One would be like the MBA philosophy; it is a terminal degree—go out to industry, being prepared for that. So the master's degree in engineering, there are experiments going on to do that, bifurcated from the fractionalization of the creation of knowledge Ph.D., and make that an integrated program, putting things together. And there has to be a terminal degree for going out and administering.

With that, I would like to end with a quotation that I included in the beginning of my written testimony. You may know this, but it excited me because, as you know, the country is facing the fact that you really cannot help run the government unless you are educated. That is the whole point. And you do not have freedom of choice unless you are educated. That is why I think everybody this morning said that the top priority is kindergarten to 12th grade education.

One of our most intellectual forbearers, Madison, said the following as he was getting older and retired from the presidency, "What spectacle can be more edifying or more seasonable than that of liberty and learning, each leaning on the other for their mutual and surest comfort?"

So that is what the aim is.

[The statement follows:]

Testimony by Joseph Bordogna*

In our democracy, national character and economic wealth have depended from the start on a continuous blending of educational substance and the freedom to apply knowledge with both individual and collective risk. The freedom to choose is a hallmark of a good life; choice is increasingly more difficult without an effective education.

For our nation, Adam Smith set the stage for fruitful economic interchange; Jefferson, Madison, and others created the political infrastructure to allow, some would say encourage, personal talent and interest to flourish to this end. But there is a necessary interaction for this scheme to work. Throughout their writings and orations, our first leaders expressed this "subtle deal" both blatantly and between the lines. From Jefferson we have: "The people are the only safe depositors of our liberty, and they are not safe unless enlightened." Madison was just as adamant: "What spectacle can be more edifying or more seasonable than that of liberty and learning, each leaning on the other for their mutual and surest comfort?" Real "revolutionaries" they were to have offered their progeny the wherewithal to respond to changing times with alacrity.

And times do change. We enter now an era of global interdependence (Adam Smith predicted such) amid societal ambiguity and complexity, all provoked by fast-paced technological change. We are not responding as well as we should. Our educational infrastructure is richly diverse and flexible, yet studies validate that its product lags peer nations in both quality and volume. In the context of our forebearers' gift of rational government this is a frightening situation.

We have growing difficulty moving people into the workforce who can perform modest mathematical operations and who can understand the simplest of instructions. We have difficulty even producing high school graduates who can read and write. This is the minimum we owe our citizenry and we cannot even achieve that, and without that there is little chance for a decent life for all, let alone international leadership for the United States.

If we are to improve our economic growth and enhance social stability, we must certainly do more than the minimum. Our young people must be educated to their fullest potential, to truly give them freedom of choice, helping them realize the dream of Jefferson and Madison. The social costs of failing to do so are enormous.

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*Dean, School of Engineering and Applied Science, University of Pennsylvania
Philadelphia, PA 19104-6391, Telephone (215) 898-7244
Chair, Advisory Committee for Engineering, National Science Foundation
Chair, Editorial Board, Engineering Education

At the turn of this century, the industrial revolution turned the ratio of blue collar workers to agricultural workers past unity; during the present decade, the ratio of white collar workers to blue did a similar flip. Coupling this evolution of the workforce with economic analysis that credits over two-thirds of the increase in productivity since the Great Depression to application of new technologies, it is imperative that we unlease our capacity to educate well. The next turn of the ratio will be so-called knowledge workers exceeding white collar workers...where will we be if we have failed to respond to the obvious: "knowledge is the capital of the future." Increasingly, knowledge, and its application, are our most vital resources - their impact on the nation's wealth creation and social stability is singular.

Thus, we need fresh understanding and readjusted investment of our national wealth toward effective education throughout the kindergarten to doctoral (or other terminal degree) continuum. But what do we mean by an "effective" education? Do we stress specificity or generality? Do we mold minds or unlock them? Do we create slots to suit societal needs or simply let things fall where they may? There is danger in being either too rigid or too carefree with any format of education. We must teach the right thing to do as well as teach how to do the thing right. Each of us must be sensitized to the value of living, as well as living well. Each of us must be prepared to both create ideas and bring them to fruition.

As society becomes more complex and relies more and more on technology to produce, communicate, instruct, entertain, and perceive one's world, the ability to understand and apply emerging technologies will determine how fully individuals and their nations can participate in the "pursuit of happiness."

Engineers are at the nexus of technological change; much responsibility for leadership in the future way of the world lies at their door. How do we prepare our budding engineers to fulfill this destiny?

Our need for well-educated enlightened engineers is critical; our ability to produce them is currently at risk. Consider the following developments:

- Full-time undergraduate engineering enrollments have been decreasing for the past six years. In the fall of 1983, 292 engineering schools reported a total enrollment of 406,144 and, in the fall of 1988, 320 schools (essentially all of them) reported an enrollment drop of 60,000 to 346,169.
- The number of full-time candidates for master's degrees in engineering dropped from 43,219 in the fall of 1987 to 41,633 in the fall of 1988.
- Gains at the doctoral level in engineering were caused entirely by an increase in the number of foreign nationals pursuing the PhD.
- The retention of underrepresented groups in academic programs and professional practice continues to be difficult.
- The necessity for engineers to change specialties over a career as technologies wax and wane has become more imperative.

These are disturbing facts. They tell us that we can expect a dearth of engineers needed for the next century. They also tell us that we are losing the potential contribution of a large segment of our population - women and minorities.

How do we turn this around? There are reasons to be optimistic. Compared to peer nations our university system is richly diverse, encourages experiments in learning, and has a far less rigid professorial hierarchy than other nations. Japanese universities, for example, suffer from a rigid faculty seniority system, rote learning, and a stifling of individual creativity by concentrating on a collective mold. Furthermore, Japanese government support of research in industry to the neglect of its universities yields little in academic quality.

Also, change has been underway for some years. There are a variety of ongoing and new efforts from kindergarten to 12th grade that hold great promise; there have been a number of serious studies of engineering education during the past several years which have developed a consistent set of recommendations for better preparation of our students for the challenges ahead; there are direct ways to enrich the value of our engineering graduate programs so that they are attractive to a larger pool of the most capable students; and the lure of leadership for faculty in academe can be made infectious (see attached bibliography).

A vision of engineering education for the start of the twenty-first century can be based on the notion that the engineer's essential role in organized society is an integrative one, i.e., an emphasis on "construction of the whole," if you will. The primary goals of an engineering education, therefore, should be to develop, in as individualized a way as possible, each student's:

- Integrative Capability: the recognition of engineering as an integrative process in which analysis and synthesis are supported with sensitivity to societal need and environmental fragility;

- Analysis Capability: the critical thinking which underlies problem definition (modeling, simulation, optimization) and derives from in-depth understanding of the physical, life and mathematical sciences, the humanities and social sciences;

- Innovation and Synthesis Capability: the creation and elegant implementation of useful systems and products including their design and manufacture;

- Contextual Understanding Capability: the appreciation of the economic, industrial, and international environment in which engineering is practiced and the ability to provide societal leadership effectively.

Each of these goals contributes to the fundamental purpose of education: the enhancement of enthusiasm and the ability to learn on a career-long basis. Present and future demands of engineering practice and societal participation require engineers to have well-developed learning skills and to be adaptable to rapid technological change as well as change in the global marketplace.

Further consideration suggests that the process for realizing these goals is centered on:

- Development of human intellectual resources;

- Development of instructional materials and educational delivery systems;
- Creation of innovative and effective laboratories that use resources efficiently.

Baccalaureate engineering education must be considered as part of a continuum of education from K-12 through the baccalaureate to graduation and beyond. In this sense, undergraduate engineering education programs supported by the government should take cognizance of the pre-college interface at the front end and the master's/doctoral/industrial interface at the output end. In the long term, the improvement of K-12 education will do much to enrich the four-year baccalaureate experience but, in the short term, educational experiments to radically alter the first year or two of a collegiate program may have great impact and are in order. In a corollary fashion, short term restructuring of engineering education at the undergraduate/master's interface should be considered both to improve the undergraduate experience and to allow a clearer distinction to be made between a practice-oriented master's degree and a research-oriented doctorate.

Additionally, there should be a rational and considered response from the engineering profession to the need, by all citizens, for a basic understanding of the technological principles that govern the global marketplace and the ability to analyze critically the many variables involved. This need has become increasingly important as the nation encounters increased world competition.

Based on these precepts, a 1988 National Science Foundation (NSF) Workshop on engineering education developed recommendations intended to drive sweeping changes in engineering curricula and in the way engineering education is done, thereby nurturing young people to pursue both challenging industrial and dynamic academic careers. While the number of faculty evolving from the latter career-path pales in comparison to the larger cadre of their industrial peers, nonetheless they represent the engine for continual renewal of the U.S. human technological resource base and must be developed with special care.

The actions recommended by the Workshop focus on human resources, creation of materials for educational use, and the transportability of those resources throughout the nation's engineering education system. In addition to nurturing young people in engineering, these recommendations also stress the need to spread an understanding of technology throughout society as a whole by including engineering concepts in the liberal arts and business educational experiences.

The actions recommended are to:

- fund the development of a variety of freshman/sophomore courses taught by engineering faculty and focusing on the integrative nature of engineering to serve the dual purpose of starting an engineering student's education with the core methodology of the engineering process and offering a substantive experience for non-engineering majors;
- increase substantially the funds available for developing new educational techniques, instructional materials, and delivery systems as well as innovative and effective laboratories;

- create a doctoral loan program for U.S. nationals that is faculty-mentored and requires teaching by the doctoral candidate to facilitate entry to a faculty career in engineering by forgiveness of the loans over the first several years of academic service;
- focus attention on recruiting and retaining women and underrepresented minorities throughout engineering including graduate and undergraduate fellowships and the doctoral loan program;
- support the development of programs that lead to a better understanding of foreign cultures and languages and the practice of engineering on a global scale;
- support professional development programs for faculty so they can include new technological developments and educational methods in their teaching;
- encourage engineering education institutions to rethink the undergraduate/master's level interface by funding curricular and course development programs which lead to articulation and integration of these programs, as well as enhanced practice-oriented content;
- alter NSF programs for awards to faculty and students to include an emphasis on the commitment to combined teaching and research for producing the scholarly leaders in academe; e.g., the criteria used in NSF Presidential Young Investigator (PYI) awards should stress that teaching as well as research is essential.

The NSF has created an exciting new slate of programs aimed to accomplish these recommendations but funding support has been inadequate to the task and its urgency. In particular, the budgets for the several NSF undergraduate programs offered in FY 1988 (Undergraduate Curriculum Development in Engineering; Undergraduate Curriculum Development in Mathematics: Calculus; Instrumentation and Laboratory Improvement; Undergraduate Faculty Enhancement; Research Experiences for Undergraduates; Career Access Opportunities in Science and Technology for Women, Minorities and the Disabled) do not even begin to address the need: the budget requests of the proposals for each of these programs were many times the funds available; this response showed that there are a great variety of significant ideas offered by the community, a large number of capable citizens ready to contribute their considerable talents to the cause, but, for lack of adequate funding, execution is stymied. The Workshop participants thus concluded that there is no way out of the worsening dilemma other than to move ahead deliberately and recapture the spirit of forward progress and leadership the nation once held. There is no equivocation about the conclusion.

To press action on the above recommendations, a 1989 Ad Hoc NSF Task Force recommended further that the NSF program on undergraduate curriculum development in engineering be expanded boldly to establish a number of consortia of academic institutions to undertake the comprehensive study, experimentation, and evaluation of undergraduate engineering education developments. These consortia would involve alliances of institutions of like kind or of two-year and four-year undergraduate institutions with universities having major research and graduate programs, or other education-related organizations. These groupings should make a multi-year commitment to focus efforts on one or more broad engineering education topics. Typical topics include developing innovative curricula, attracting

and retaining students of diverse backgrounds and aptitudes, enhancing the quality of the faculty as scholars and teachers, and fostering couplings among scientific institutions and industrial companies to strengthen linkages to engineering practice.

Thus, we head into the 1990s with the reports written, consensus on recommendations, and a growing national will to "work it all out." With appropriate funding, there is great confidence that activities aimed at significant change in freshman to higher education in engineering will succeed nicely. In tandem, things also bode well for increasing the pool of high school graduates qualified to be educated as engineers. However, there is no guarantee that a sufficient number of these better-educated youngsters would choose careers in engineering without an additional effort to motivate them to such an end. After all, engineering is a demanding field of study, involving a bit of courage and a lot of investment to pursue. Success can be garnered by involvement of engineering faculty and industrial engineers with students and teachers throughout the K-12 years. Here, again, things are in motion, particularly for regional consortia originated for this purpose. Two highly successful programs, in both quality and quantity, are PRIME and PRISM.

PRIME is a nonprofit corporation devoted to creating opportunities for minorities in engineering, pharmacy, and other mathematics and science-based professions. It was founded in 1973 and incorporated in 1975 as a partnership of area businesses, government agencies, local colleges and universities, professional associations and parent groups, all working together to identify and prepare minorities for careers in technical and scientific professions. Located in Philadelphia, Pennsylvania, PRIME offers programs to junior (or middle) and senior high school students in Greater Philadelphia, Southern New Jersey, and other parts of the Greater Delaware Valley region.

Each year, PRIME offers precollege academic enrichment and motivational services to over 3,000 students enrolled in the Philadelphia and Camden public school districts. In addition, PRIME provides academic counseling, tutorial assistance, career counseling and job referral for over 700 PRIME graduates who are presently enrolled in more than 100 four-year colleges and universities located throughout the United States. Since its inception in 1973, over 40,000 minority students (African Americans, Hispanics, Native Americans) have been active participants in the PRIME program. Of those students, it is estimated that 72% or 28,800 have obtained or are currently pursuing a degree in engineering or some other science-related field.

PRIME programs begin at the seventh grade, where capable minority students are identified on the basis of test scores and other indicators (i.e., teacher recommendations and scholastic achievement) as having a strong aptitude and interest in mathematics and science subjects. Once identified, students are provided with intensive and supplementary educational activities in mathematics, science, and communications. They are carefully monitored and counseled for their remaining five years of pre-college schooling. At the college level, students continue to be monitored and counseled. During the summers while in college and after graduation from college, they also receive job referral and placement assistance.

As a pre-college program, PRIME's major focus is on preparing minority students at the middle and secondary level for careers in mathematics, engineering, and science-based professions. Toward this end, PRIME's programs are divided into two major components: an academic year component and a summer component. During the academic year, PRIME programs consist of enrichment, motivational, and skills development activities. At the junior (or middle) high school level, students are enrolled in special PRIME classes where they are provided with information and enrichment activities which illustrate applications of mathematics, science, and technology in solving real world problems. At the senior high school level, major program emphasis is placed on helping students develop and acquire prerequisite skills and knowledge to successfully enter and complete a technological and/or scientific college degree program. Students are counseled on what subjects to take, how to prepare for college entrance examinations, how to select an appropriate college, and how to obtain financial aid.

During the academic year, students also receive career information and hands-on experiences from industry and government representatives who make monthly classroom visits. Each company and government agency that is a member of PRIME is linked to a PRIME school. This industry-school linkup provides opportunities for member companies to interact with PRIME students one-on-one through classroom presentations, mini-demonstrations, and field trips. Company representatives play a crucial part by serving as role models and resource persons for PRIME students.

During the summer, PRIME offers university-based training programs to its most talented students. These programs are designed to sharpen students' skills in reading, writing, mathematics, computers, engineering, chemistry, biology, and related sciences. Programs begin at the post-7th grade and continue throughout the post-11th grade levels. A special segment of PRIME's summer programs, known as the PRIME Universities Program (PUP), offers four weeks of sequential and intensive instruction beginning at the post-8th grade level and ending at the post-11th grade level, where students participate in a residential program. Universities participating in PRIME's summer programs include Drexel University, Philadelphia College of Pharmacy and Science, Temple University, University of Pennsylvania, and Villanova University. Programs are also offered at Camden County College and the Philadelphia Naval Shipyard.

In 1988, PRIME served 3,200 students through its academic year programs, and 543 students through its summer programs. Based on recent program statistics, approximately 99% of PRIME high school graduates enter college and 72% enter technical and/or engineering degree programs. Of these students, approximately 85% graduate from college and enter engineering, pharmacy, allied health, and other mathematics and science-based careers.

PRIME has received national recognition as a model pre-college program. Similar programs in Boston, Buffalo, Dallas, Detroit, the District of Columbia, Rochester, and New Orleans have been designed to follow the idea pioneered by PRIME more than fifteen years ago: a consortium of local businesses, universities, and school systems to address what has become a national epidemic of mathematics and science illiteracy among students. The President's Task Force on Voluntary Initiatives has described PRIME as "a conspicuous example of how private sector initiatives, in partnership with urban education systems, can enhance the quality of urban education through the optimal utilization of resources directed by a single focus."

PRIME recognizes the need to reach more students and is committed to increasing its services to enhance the educational experience of a larger

student population. This year the board of directors of PRIME has initiated a five-year plan designed to increase the number of students who receive PRIME's services by 20% each year, thereby more than doubling the current number by 1994.

As PRIME developed and prospered during the late 1970s and early 1980s as a partnership to develop the talents and interests of students, another dream of the Philadelphia activists in pre-college affairs came to fruition: a partnership for teacher and curriculum development with coupling to student services. This organization is known as PRISM (Philadelphia Renaissance in Science and Mathematics) and, early on, it linked to PRIME for its student base.

PRISM was founded in 1985 as a non-profit public/private partnership to assist teachers in the School District of Philadelphia in their effort to strengthen the effectiveness of instruction in science and mathematics. In 1987, PRISM merged with PATHS (The Philadelphia Alliance for Teaching Humanities in the Schools) to form PATHS/PRISM: The Philadelphia Partnership for Education, the country's largest, most comprehensive partnership for staff and curriculum development. A program of the Committee to Support Philadelphia Public Schools, PATHS/PRISM represents colleges and universities, museums, cultural and scientific organizations, foundations, and corporations, in partnership and collaboration with the School District of Philadelphia.

There are three categories of PRISM programs: (1) elementary/middle school teacher-based, (2) secondary school teacher-based, (3) student-based. The status of these programs follows:

Elementary/Middle School Teacher-Based

Elementary Science Kits

Begun in 1985, this project represents collaboration at its best, drawing on the experience and expertise of its partners: the Franklin Institute Science Museum, the School District of Philadelphia, and PRISM. Bringing a "hands-on" approach to elementary science education, this program has become a model for innovative science programs nationwide. With funds from the Pew Charitable Trusts, the School District, and the National Science Foundation, PRISM helps implement a five-year plan to provide four science kits per year to all elementary school classes (grades 1-6) in the District. This year, more than 54,000 students are using these science kits which provide year-long hands-on materials to carry out scientific investigations in the classroom. Teachers who receive the kits are trained in science and kit usage. In those classrooms where the kits are fully utilized, the children are receiving a rich experience in laboratory science.

Light, Heat, and Motion

Begun in the summer of 1988 with funding from the Pew Charitable Trusts, this project is designed to enhance the effectiveness of elementary and middle school science instruction by improving the scientific and mathematical background of elementary and middle school teachers through a series of summer institutes and academic year programs. Focused each year on a central theme (Light, Heat, and Motion), these five-week interdisciplinary summer institutes provide teachers with additional materials and a deeper understanding of the underlying concepts. During the academic year follow up, each team of teachers conducts at least two staff development workshops; the teachers take the lead in improving science instruction in their schools by expanding the background knowledge of their peers and familiarizing them with a variety of "hands-on" classroom activities that emphasize process skills.

Supported now by a three-year Teacher Enhancement grant from the National Science Foundation, the 1989 Summer Institutes in Heat and Light were held at Drexel University and the Franklin Institute Science Museum. Seventy-six participants from thirty schools (sixteen teachers were from the schools of the Archdiocese) completed the five-week summer courses. Over the 1989-90 school year, teams will present staff development workshops and will act as resources for their colleagues at their schools.

Professional Development Workshops

Teacher-to-teacher Professional Development Workshops are led by teachers who have had staff development training from PRISM or from other college or university programs. These workshops, which take place in both elementary and secondary schools in both mathematics and science, evolved from recommendations made by PRISM's Teachers Advisory Group in direct response to needs expressed by classroom teachers. Topics for the workshops include hands-on activities for elementary and middle school science, computer modeling, computer interfacing, and new techniques in mathematics instruction. There were 22 workshops, held during department meetings or after school hours, in the spring of 1989 involving a total of 436 teachers. Eleven workshops were given in science and ten in mathematics at thirteen elementary schools, three middle schools, and five high schools. Four workshops were funded by a grant of $1500 received from Chevron USA, Inc. These ad hoc projects are cost-effective and are often developed into regular programs. The enthusiastic response from teachers participating in this round of workshops has made it necessary to promise a second round of workshops this fall.

Critical Thinking Workshops

Sponsored by the IBM Corporation, PRISM has conducted innovative summer courses at the IBM regional headquarters in 1988 and 1989 to provide middle school teachers with an intensive learning retreat focused on mathematics and critical thinking. The workshop, Critical Thinking for a Technological World, involved teachers in a multi-faceted seminar emphasizing the interconnectedness of science, mathematics, and technology. Sessions ranged from lively discussions of the philosophy, meaning and purpose of science through investigations of mathematical language and expression. Participants had opportunities to use IBM professional and educational software. They participated in unstructured experiences designed to raise teacher awareness of critical thinking processes and examined books, periodicals, games, videos and manipulatives that could serve as instructional tools for the enhancement of critical thinking.

PRISM Project for Mathematics Manipulatives (P2M2)

Supported by a planning grant from the Exxon Education Foundation, PRISM has established a committee comprised of lead teachers, district supervisors, a professor from the University of Pennsylvania, and secondary and elementary mathematics specialists, to develop mathematics manipulatives kits which will provide hands-on materials for students similar to the Elementary Science Kits. The goals of the project are to develop two kits (one for grades 1-3, another for grades

4-6), write teachers' guides for their use, and provide workshops for teacher training. After discussions about the types of materials to be included in the kit, the committee selected items which would support concept development through multi-purpose utilization. Pedagogical effectiveness is the major factor in the selection of manipulatives, but multi-purpose application and cost were also considered. The committee has discussed the selection of pilot schools and teachers along with methods of monitoring and evaluating a pilot. Future tasks of the P2M2 committee include the development of teachers' guides for kit activities and the formulation of a staff development model. The results of this year's planning will be used to prepare a grant proposal for implementation of the mathematics manipulatives kits on a pilot basis.

Secondary School Teacher-Based

The Science Teacher Enrichment Program (STEP)

Supported by the Pew Charitable Trusts, a group of teachers, administrators, and university faculty met to design and plan a program which focuses on staff development for secondary school chemistry, physics, and physical science teachers. Special emphasis was placed on updating current knowledge in various rapidly developing fields, integrating science and mathematics, and providing supporting activities related to the planned reorganization of comprehensive high schools in Philadelphia. In response to the needs and interests of teachers, a five-week course in Physical Chemical Principles and Applications of Lasers was given last summer at the University of Pennsylvania to twenty-six teachers from sixteen high schools. The course focused on the academic content required to update the teachers' background knowledge, as well as the articulation of this information with the current high school curriculum and with pedagogical techniques. The extensive academic year follow-up program consists of teacher-to-teacher workshops, individual projects, and curriculum development. Each teacher received three credit hours from the Department of Chemistry at the University of Pennsylvania, a stipend, and a laser.

Woodrow Wilson Institutes for High School Teachers

PRISM administrates two one-week sessions in chemistry and mathematics at an area college each summer. The institutes are co-sponsored by the Woodrow Wilson National Fellowship Foundation and are open to all teachers. In 1988 and 1989, PRISM provided tuition support for Philadelphia public school participants. Participants were also offered a grant of $200 for costs to formally share the experience with their colleagues. In the summer of 1989, the courses in chemistry and mathematics (geometry) were held at the Philadelphia College of Textiles and Science. PRISM's involvement in this highly-regarded series of courses given by Lead Teachers is mainly in terms of administration, tuition support, and follow up.

Philadelphia Math/Science Collaborative

The Math/Science Collaborative provides joint programs and evaluation services for teachers. One of the most successful programs has been the incorporation of computers and software in teaching geometry. In addition, teachers are awarded enrichment grants in order to attend conferences and join professional organizations, and they receive a monthly newsletter. In 1987-88 there were nine target schools, and this year there will be twenty involving about 370 mathematics and science teachers. This year the coordinator and program officer will be supported by the Philadelphia Schools Collaborative and the School District, respectively. Program costs are funded by the Ford Foundation and PRISM.

Philadelphia Teachers in Industry Program

Through PTIP, public school science and mathematics teachers have the opportunity to become involved in the latest corporate-based applications of science and mathematics, and to carry this knowledge and experience back to the classroom. The year-long program begins with a full-time summer placement at area corporations from which PTIP fellows receive a stipend. The companies involved have found that teachers make significant contributions to company operations during their assignments. During the academic year, PTIP fellows are required to share their experience and knowledge with their students, colleagues, and school counselors through follow-up activities such as new lesson plans, written articles, staff meetings, colloquia, and workshops. As a result, PTIP fellows help public school students learn more about a world of which academically-trained teachers usually know very little. Last summer's sponsors were ARCO Chemical, Westinghouse, Sun Company, Rohm and Haas, Bell of Pennsylvania, Pennsylvania National Bank, AT&T, Cigna Corporation, and SmithKline Bio-science Laboratories.

Student-Based Programs

Comprehensive Regional Center for Minorities (CRCM)

PRISM, as the representative of the Greater Philadelphia Regional Consortium, has received a large grant from the National Science Foundation for a five-year program to establish a Comprehensive Regional Center for Minorities (CRCM) to increase minority access to education and careers in science, engineering, and mathematics (SEM). The consortium is comprised of four metropolitan school districts, thirteen universities, colleges, and community colleges; museums; corporations; non-profit partnerships; and minority community organizations. Year I will be spent in the assessment, coordination, and expansion of existing regional minority SEM programs, such as PRIME, other university-based programs, and in the planning of new activities. Support components will consist of a computerized tracking system and a resource center. The central programmatic strategy of the CRCM will be to focus on the introduction to and retention of minority students in the SEM pipeline from the first grade through completion of a graduate degree, with the integration of three principal components: pre-college professional development programs in science and mathematics for teachers, counselors and parents; pre-college student programs; and college-level programs.

PRIME

PRISM funding has enabled PRIME to expand its efforts to increase the enrollment of minority students in upper level courses in science and mathematics, and to attract these students into mathematics, engineering, and science-related fields. During 1988, PRISM funding enabled PRIME to increase its enrollment of minority students in the summer university program by fifty students. Another grant from the National Science Foundation has enabled PRISM and PRIME jointly to hire staff to recruit minority students in public and private schools. Two part-time recruiters working out of the PRIME office are concentrating their efforts on the School District of Philadelphia and have already augmented the cadre of School District PRIME schools. A PRISM program coordinator is working half-time recruiting students in the Schools of the Archdiocese of Philadelphia. This year, six K-8 Catholic Schools are adding approximately fifty new students to the PRIME Universities Program (PUP) at the post-eighth grade level. In 1989, 722 students attended PRIME's summer courses. Of the 214 PRIME students who graduated this year from high school, 197 (92%) were accepted to colleges and universities.

SmithKline Visiting Scientists

Funds from the Pew Charitable Trusts have enabled PRISM to coordinate a program offered by SmithKline Bio-Science Laboratories in which research scientists visit classrooms in pairs and give talks illustrated by slide programs. The purpose of the program is to encourage students to keep their career options open by taking advanced science and mathematics in high schools. This year, SmithKline research scientists spoke at twenty-three schools to over 2000 eighth graders. Students' questions demonstrated an appreciation for the importance of medical science, and they were impressed by the scientists' descriptions of the hard work and dedication needed, as early as in high school, to succeed in a scientific career.

JOINT PATHS/PRISM PROGRAMS

Grants for Teachers and Schools

In 1989, PATHS/PRISM awarded 144 mini and collaborative grants ($300 for an individual teacher's school-based project and up to $3000 for a team of two or more working together with resource people from area universities, scientific and cultural institutions, and corporations) for a total of $152,000. There were a record number of applicants with innovative proposals which involved students in problem-solving activities in science and mathematics. PRISM awarded a total of $58,000 in 1989 and $48,000 in grants in 1988. The incorporation of the annual PATHS/PRISM Grants Fair this year into the Philadelphia Federation of Teachers' Health and Welfare Conference resulted in a several-fold increase in teachers who saw the displays of past grant winners. Two new categories of awards, Dissemination Grants and PATHS/PRISM Interdisciplinary Grants, were created this year.

Project 2061

Philadelphia has been chosen by the American Association for the Advancement of Science as one of six national sites for Phase II of Project 2061, a long-term effort to improve scientific literacy in this country's students. For Philadelphia, PATHS/PRISM is the facilitating agency. A 25-member team has been selected which will, over the next two years, design a national model for a science curriculum in an urban setting. The Task Force consists of five elementary teachers, five middle school teachers, ten secondary teachers, and five administrators. In July, the team attended a four week summer institute in Boulder, Colorado, followed by a two week workshop in Philadelphia at the University of Pennsylvania. Work will continue through the academic year, 1989-90 and 1990-91, with a second summer institute in 1990. For each of two years, team members will be released from class forty days (four days a month) and be given a space at Drexel University to gather and work. Area universities have made a commitment to provide intellectual and technical support. In addition, each member of the team and the facilitating agency will receive an IBM PS2/30 computer with modem, printer, and software. The team will submit the final draft of the model curriculum to the AAAS by the end of May 1991.

Results of PRISM Programs

The region's colleges, universities, scientific and cultural institutions, and private corporations recognize PRISM as the major community organization for collaborating with mathematics and science teachers for staff development within the School District of Philadelphia. PRISM programs have served more than 2,000 teachers, while involving over forty corporations, nine universities, and numerous museums and other institutions. Documented results include the following:

- The proportion of high school students (grades 10-12) enrolled in higher level science courses has increased by 20% since 1984. The proportion enrolled in higher level mathematics courses has increased by 30%.

- A massive five-year $5 million program to provide science kit materials and training for some 6,000 elementary teachers is underway with great success. Initial results indicate that students who have participated in this program score 16% higher than other students on curriculum-referenced tests.

- The number of students served by PRIME programs has more than doubled, now reaching more than 3,000 students, including 722 students active in the university resident/study program. There has also been an increase in the number of PRIME graduates who enroll in college as science or mathematics majors and who go on to pursue graduate degrees and careers in those fields.

- The number of teachers directly involved in PRISM leadership summer institutes has increased to over 200 in 1989. There are Lead Teachers trained by PRISM in some 100 schools in the District.

Programs such as PRIME and PRISM are working well in attracting students to engineering careers. They and their counterparts across the country can take some pride that in the fall of 1988, the number of underrepresented minority students rose a healthy 13.8% (to 11,754 from 10,325 in fall 1987). It is very interesting to note that while total undergraduate engineering enrollment decreased by 10,568, underrepresented minority enrollment increased by 1,413.

SUMMARY: The studies have been done, the reports written, consensus is in hand, and a budding supportive infrastructure has developed. With appropriate investment, the future of U.S. engineering education and practice can be bright indeed. In addition to private sector support, NSF programs toward this end are well-conceived, enjoy broad-based understanding, and projects are underway. Here particularly, investments can result in early improvement of our present state.

Senator **Gore**. Thank you very much.

Our final witness is Mr. Daniel F. Burton, Jr., Vice President of the Council on Competitiveness located here in Washington, and I think it is only appropriate that we both begin and end today's hearing with a Tennessеean.

We are delighted that you are here.

STATEMENT OF DANIEL F. BURTON, JR., VICE PRESIDENT, COUNCIL ON COMPETITIVENESS

Mr. **Burton**. Thank you very much, Mr. Chairman. If you had not made that comment, I was going to and so I appreciate those words of wisdom.

Dr. **Bordogna**. But where is your degree from?

Mr. **Burton**. Actually, the University of Pennsylvania.

I think that there is new life to the technology debate, witnessed by these hearings and the new interest in public policy.

The new vigor to the public policy debate about technology is driven not so much by technical issues, but by economic and by social concerns.

I am going to focus primarily on the economic angle, specifically the international economic issues which I think is really driving a lot of the renewed interest, a lot of the concern about where this country stands in public policy and science and technology.

Many of my remarks will be drawn from a council report entitled Picking Up the Pace: The Commercial Challenge to American Innovation, which focuses on U.S. industry competing in world markets.

My premise is that U.S. science and technology policy can no longer be viewed as limited to national security and basic research.

There are another set of concerns we have to take into account. Those set of concerns are strategic, economic considerations.

The primary challenge facing U.S. policymakers today, I believe, is to develop a new public policy framework for technology that addresses the reality of international competition.

While other governments have used science and technology policies to very systematically promote industrial growth, commercial spin-offs from U.S. government technology programs, if they have occurred at all, have been incidental. Because the ability of American firms to identify, develop and rapidly commercialize technology is critical to our ability to compete in world markets, it is essential for the government to promote these private sector initiatives very systematically.

What I would like to do is run through what I call five myths about the U.S. position in technology. I think these myths still determine to a large extent how people think about the United States and its technological capabilities.

If we are going to get to a new set of technology policies, we really need to move beyond these myths.

The first myth is what I call the technology dominance myth. It states that America still dominates the international market for technology, which is after all the economic key to the next century, so we do not have much to worry about.

The facts say otherwise. In 1981 the U.S. had a $27 billion surplus in high tech trade. In 1986 it recorded its first trade deficit ever, and the deep penetration that other companies have been made in the technology markets both in the United States and overseas, demonstrate that the U.S. is unlikely to regain the dominant position it enjoyed in technology during the early post-war era.

The second myth is what I call the leading edge myth. This one says, perhaps we have some problems in technology, but in the leading edge technologies that really count, U.S. companies and researchers are way ahead.

Here I would draw your attention to the chart in front of you which demonstrates the U.S. position in some technologies which were pioneered in the United States and markets which were created and dominated by American firms and industries. As recently as 1970 and the mid 1970s, the U.S. enjoyed a very strong position in these industries.

What we see is that there is a slippage of U.S. performance in technology-intensive industries. It is not only related to what we call low tech consumer electronics things like phonographs, televisions, VCRs. It also goes into some core manufacturing areas—machine tools, semiconductor manufacturing equipment, ball bearings, it all also extends all the way up into some very high-tech sectors, such as semiconductors and FAX machines, and fiberoptics, where you see the same trend—rapid erosion of the U.S. position in world markets.

So, I think we can no longer comfort ourselves with the fact that when it comes to leading edge technology, the U.S. has a lock on the international marketplace.

The third myth is what I call the copycat myth. This myth says, well, perhaps the U.S. does have some problems in technology. Perhaps they extend all the way through from some low tech industries up into some very high tech industries.

But, in fact, we do not have that much to worry about because we are the supreme innovators. Other countries are really capable only of copying new discoveries, new breakthroughs that come out of this country. Therefore, all we need to do is protect our intellectual property a little better, and we will be well positioned to succeed in future world markets.

The facts, again, tell us to beware. One half of U.S. patents now go to foreign inventors and an increasing number of core patents are going to foreign inventors. The breakthroughs in such areas as high definition television and superconductors demonstrate that, in fact, other countries are quite capable of pushing through innovation and breakthroughs on their own.

The fourth myth is what I call the Nobel prize myth. To continue the continuum, it says, well, perhaps, we do have these problems in technology. They go all the way to high tech. They may include innovation. But when it comes to technology infrastructure, the U.S. is number one. We are supremely preeminent here. After all, we win all the Nobel prizes; students from around the world come to study at U.S. universities; U.S. technical articles are cited overwhelmingly in world journals. Our infrastructure is really what gives us a leg up in world markets.

In fact, there is a lot of validity to this statement. However, we cannot ignore the fact that there are serious problems with the people, the facilities, and the equipment that make up U.S. technology infrastructure, as the computer network bill that you have introduced has demonstrated and as Dr. Bordogna has mentioned.

The final myth relates to policy choices. It is what I call the Sputnik myth. This myth, says that, well, perhaps we do have all these problems. A new profile for public policy and technology is required. But, in fact, we do not have that much to worry about because if you look back to the last big technological challenge the U.S. faced—Sputnik in the 1950s—you saw a very clear, definitive and aggressive public policy response that addressed those issues and set the country back on the right course.

The difficulty that we face today is twofold and really sets us apart from the situation we faced in the late 1950s.

First of all, there is no one single event around which to rally public policy. There is not a Sputnik.

Our chairman, John Young, says he thinks it would be helpful if Toyota were to launch a car into outer space. Perhaps that would grab public attention. But so far we do not have a single event around which to rally public policy.

The second concern—and this is changing to some extent—is that the challenge we face in technology today is primarily a commercial challenge. It is not—at least not so far—a military or national security challenge. There are national defense issues to consider, but the commercial challenge is the big problem confronting us, and our public policy machinery is not set up to deal with commercial technology issues.

Current U.S. science and technology policy is based to a large extent on these myths. It is based on a view of U.S. industry and a view of the U.S. technological infrastructure and technological abilities that simply are not consistent with current international reality.

If we are to structured new science and technology policy that takes into account international competition, we have to recognize these myths for what they are and put together policies that correspond to the new reality.

I would like to conclude by making some brief statements about four areas that are critical to the whole technology policy debate. In each of these areas there is increasing consensus. There are some experiments and a willingness to try something new, which offer potential for future progress.

The first area, is strengthening the U.S. manufacturing base. One of the lessons that came out of the 1980s is that manufacturing and technology are not two separate, divorced areas. Technological strength relates very, very closely to a strong manufacturing base. We cannot lose sight of that if we are going to be competitive in world markets in the future.

When you talk manufacturing, the two issues which emerge immediately are cost of capital and short-term time horizons of management. I do not have any wisdom or solutions to pose in those two areas except to say I think when we talk about short-term time horizons of American management, in fact what we are talking about is a growing tension between the financial sector of the U.S. economy and the manufacturing sector of the U.S. economy.

The financial sector is driven by short-term incentives. It is driven by high investment opportunities that can produce results or income today.

The manufacturing sector, by definition, is driven by long-term time horizons, and require massive investments up front that do not have payoffs for long periods of time. If we really are going to get at this manufacturing question, we somehow have to get at the tension between the financial and the manufacturing sector.

The second issue which has been commented on at length this morning is the policy-making machinery for technology. It is fragmented in the Federal Government. There is no one agency with a real overview for technology policy, nor is technology often on the table when we talk about the larger policy discussion of the day.

The third area is upgrading U.S. technology infrastructure. I think, again, there is broad consensus here. There is a recognition of actions that we have to take and a willingness to do so.

The fourth area is widening national R&D efforts: cooperative R&D, state efforts, links between universities, government, private sector, all of those are part of that effort.

In conclusion, then, I would just like to say that we need to move past the mythology—the very comforting mythology—of U.S. dominance in world markets. We need to recognize the fact that there is no silver bullet. Progress is going to entail progress in all four of the areas that I have outlined. And finally, to reassert my premise, that what we need to do in public policy for technology is to determine how technology policy can accommodate strategic economic concerns, as well as basic research and national security.

Thank you very much.

[The statement follows:]

STATEMENT OF DANIEL F. BURTON, JR., VICE PRESIDENT, COUNCIL ON COMPETITIVENESS

In field after field -- from consumer electronics to machine tools and semiconductors -- foreign competitors have succeeded in markets pioneered and once dominated by American firms. Ironically, many foreign commercial successes have been built on exploiting inventions made in American laboratories by American scientists. Although U.S. firms may have advantages in cutting edge research, foreign competitors have done a better job of moving new technology from the drawing board to the marketplace. By aggressively commercializing new technologies, foreign competitors have achieved considerable economic success, sometimes taking over entire industries.

Foreign success in the rapid commercialization of technology has triggered public recognition of the fact that in today's international economy, virtually all aspects of technology have become globalized. The new globalized scientific and technical community has profound implications for corporate strategy and public policy. The United States, long used to preeminence in science and technology, has been slow to recognize the changing nature of technological competition. As the nation wakes up to this new reality, it must reassess the role of the private sector and the policy context in which it operates.

The New Competitive Environment

International competition is changing our perception of R&D and the innovation process. When the United States was primarily a domestic marketplace, the pace at which technology was turned into new products and processes was only one of several factors that determined commercial success. Today, with companies from around the world vying to gain competitive advantage from technology, the speed with which firms are able to translate innovations into commercial products and processes often spells the difference between success and failure.

America's post-war preeminence in technology resulted largely from its ability to master the "research-driven" model of innovation, which views the innovation process much like a relay race. A scientist doing basic research comes up with a new discovery. He then hands off the discovery to the applied researcher, who develops a new product idea. The applied researcher, in turn, hands off the new idea to the engineer who develops a working model. The engineer then hands it off to the manufacturing department, and, so on, through marketing and distribution.

International competition has turned this view of innovation upside down. Following the devastation of World War II, other countries could not compete with the United States by building the infrastructure and training the people necessary to do path-breaking basic research. It was simply too expensive and too time-consuming.

Instead, they made up for their shortcomings in basic research by acquiring technology from abroad -- often from the United States -- and concentrating their industrial resources on the rapid commercialization of new ideas. They focused on winning in world markets, not by doing basic research, but by finding new market applications for existing technology and rapidly translating technology into new products and processes. Aggressive market research, excellence in manufacturing, attention to quality and a low cost of capital are the key elements of this strategy.

Unlike the linear model of innovation, with its similarity to a relay race, the market-driven model is more like a basketball game. Success depends on a coordinated team effort, with researchers, engineers, and marketing personnel constantly passing the ball back in forth as they move forward.

Since competing technology can be generated worldwide, companies must place increased emphasis on monitoring international sources of innovation, protecting their own technical positions and participating in many national technical communities. In short, companies must be as much "hunters and gatherers" of technology as they are generators, and public policy must take into account the impact of international competition on the commercial application of technology.

The Five Myths of U.S. Leadership in Technology

Although the competitive environment has changed, many Americans continue to cling to the outdated view of U.S. supremacy in science and technology. This view is based on conditions that prevailed in the early post-war era that no longer hold true today. It is premised on five myths. Like all myths, there is an element of truth in each of these assertions, but we cannot afford to accept them at face value. They portray a United

States that is preeminent in science and technology with nothing to fear from foreign competition. If we are to structure a U.S. science and technology policy capable of addressing the commercial challenge to American innovation, we must debunk these myths and move beyond the comforting illusion of unrivalled U.S. technological leadership.

The first myth is the "technology dominance myth." According to this myth, although the United States may have some problems in manufacturing, it is still number one when it comes to technology. And since technology is the economic key to the next century, problems in these other areas really are not that important.

Trade data tell a different story. As recently as 1981, the United States enjoyed a $27 billion surplus in technology trade. Unfortunately, this technology trade surplus has disappeared. In 1986, the United States ran its first-ever technology trade deficit. Some observers have blamed this deficit on the high dollar of recent years. But the dollar began to come down in September 1985. Three years later, in 1988, the U.S. posted a surplus of about $8 billion in technology trade. Given the deep penetration of U.S. technology markets by other countries and the premium they place on science and technology as a driver of economic growth, it is unlikely that the United States will soon be able to generate the kinds of technology trade surpluses it enjoyed in the early 1980s, even with a lower dollar.

The second myth is the "leading-edge myth." This myth holds that even if the United States has some technology trade problems, it still has a lock on high-technology, which is, after all, the most important sector. Although we may have lost some markets, such as consumer electronics, in the leading-edge technologies that really count U.S. companies and researchers are way ahead.

This view ignores recent experience in some key high-tech markets. The technology challenge is no longer limited to consumer electronics. Televisions, audio recorders and VCRs are not the only industries that have stumbled in the face of foreign competition. From 1970 to 1987, U.S. companies' share of the domestic American market for horizontal numerically controlled lathes and machining centers -- two core machine tool technologies -- fell from 100 percent to 40 and 35 percent respectively. During the same time period, our share of the American market for telephone sets fell from 99 percent to 25 percent; our share of the American ballbearing market fell from 88 to 71 percent; and U.S. companies' share of the American market for semiconductor manufacturing equipment fell from 100 to 75 percent. (See Table 1).

And these numbers only describe the performance of U.S. companies in their own home market. For U.S. exports, the competition in technology is even more intense.

Semiconductors, which are central to the entire computer industry, are perhaps the best example. In 1959, the first semiconductor was invented almost simultaneously by two Americans, Jack Kilby and Robert Noyce. During the 1960s and 1970s, U.S. companies dominated the world market for the design and manufacture of semiconductors and computers. In the early 1970s, however, Japan targeted semiconductors as a strategic industry. By 1980, Japanese companies had surpassed U.S. merchant semiconductor firms in the design and manufacture of the latest generation of semiconductor devices. By 1983, Japan-based firms' share of the world market was equal to that of U.S.-based firms. By 1986, Japan had taken 65 percent of the world market for memory products while the U.S. share had fallen to under 30 percent.

TABLE 1

THE EROSION OF THE U.S. SHARE OF TECHNOLOGY MARKETS

TECHNOLOGY	PIONEERED BY	U.S. COMPANIES' SHARE OF DOMESTIC AMERICAN MARKET (percent)				ESTIMATED 1987 VALUE OF U.S. MARKET (millions)
		1970	1975	1980	1987	
Phonographs	U.S.	90	40	30	1	$ 630
Televisions						
Black & White	U.S.	65	30	15	2	$ 175
Color	U.S.	90	80	60	10	$ 5,150
Audio Tape Recorders	U.S.	40	10	10	1	$ 500
Video Cassette Recorders	U.S.	10	10	1	1	$ 2,895
Ballbearings	Germany	88	83	71	71	$ 1,657
Machine Tools						
Horizontal Numerically Controlled Lathes	U.S.	100[1]	92[1]	70	40	$ 401
Machining Centers	U.S.	100[1]	97[1]	79	35	$ 485
Telephone Sets	U.S.	99	95	88	25	$ 2,000
Semiconductors[2]	U.S.	89	71	65	64	$ 19,100[1]
Semiconductor Manufacturing Equipment[3]	U.S.	100	90	75	75	$ 1,858
Cellular Telephones	Scandinavia/U.S.	–[4]	–[4]	–[4]	40	$ 740
Facsimile Machines	U.S./Japan	–[4]	–[4]	–[4]	–	$ 750

[1] Estimates

[2] Data is for semiconductor merchant companies only. U.S. company share includes production of foreign subsidiaries operating in the United States.

[3] Estimates only. No official data exists.

[4] Not introduced into the U.S. market.

Source: Council on Competitiveness compile from data provide by the International Trade Administration, U.S. Department of Commerce

So much for the U.S. lock on leading edge technology products.

The third myth is the "copy-cat myth." According to this myth, even though other countries may have caught up to the United States in technology markets, they have done so by copying us. They are incapable of real innovation on their own. This argument is often directed toward the Japanese.

While this trend was true in the first few decades following World War II, patent data tell a different story today. In 1987, 46.6 percent of all U.S. patents went to foreign inventors, up from 35 percent in 1975. Furthermore, in an increasing number of fields the important patents are held by foreign inventors. Starting more than a decade ago, patents awarded to Japanese inventors were cited more frequently by those applying for new patents than those awarded to Americans. And this gap appears to be growing.

Breakthroughs in such emerging technologies as high definition television and superconductors show that these patent data are not just an academic concern. Japan and other countries are now perfectly capable of inventing and developing leading edge technologies on their own. As a result, they stand to reap considerable economic rewards.

The fourth myth is the "Nobel prize myth." It holds that even if other countries are making progress in technology, the United States still has the premier technology infrastructure. American citizens have won an increasing number of Nobel prizes in each post-war decade; U.S. technical articles are cited overwhelmingly in many fields; and students from around the world come to study at U.S. universities.

But these successes do not mean that there are not serious deficits in the people, equipment and facilities that constitute our technology infrastructure.

The numbers are startling. American students consistently score lower on international math and science tests than their counterparts in other industrial nations; 1,300 to 1,800 engineering faculty positions at U.S. colleges and universities are currently vacant; according to NSF estimates, some 60,000 high school math and science teachers are not adequately qualified to do their jobs; and the nation faces a projected shortfall of over 500,000 scientists and engineers by the year 2010. Over the past two decades real federal investments in university research facilities has dropped by 95 percent. These are not trivial developments.

The fifth myth is the "Sputnik myth." This myth also downplays the challenge to U.S. technology. It implies that once the federal government recognizes the severity of the problem, it will take quick and decisive action to restore U.S. leadership, just as it did after the Sputnik crisis.

This view ignores two facts. First, unlike the Sputnik crisis, the challenge to U.S. leadership in technology does not have a signal event around which to rally public policy. Instead, it results from a long erosion of the U.S. position. While we have been caught short on many of the necessary investments, other countries have made excellence in science and technology a national priority.

Second, the challenge to American technological leadership is primarily a commercial challenge, not -- at least, so far -- an overriding military or national security challenge. Consequently, it is difficult to determine what the proper public policy response should be. After all, the commercialization of technology is a private sector responsibility. And the U.S. economy is based, in premise if not always in practice, on limited government involvement in the marketplace.

These five myths about the U.S. position in science and technology demonstrate that the challenge to U.S. leadership is real, that it is diverse and that it calls for a different kind of public policy response than we are used to.

The Role of Public Policy

The primary challenge facing U.S. policymakers today is to develop a new public policy framework for technology that addresses the reality of international competition. While other governments have used science and technology policies to promote industrial growth, commercial spin-offs from U.S. government programs, if they have occurred at all, have been incidental. Because the ability of American firms to identify, develop and rapidly commercialize technology is critical to our ability to compete in world markets, it is essential for the government to promote these private sector efforts systematically.

U.S. science and technology policy is based in large part on the mythology of unrivalled leadership. Because it is assumed that the United States still enjoys a dominant world-wide position in science and technology, U.S. policymakers tend to view these issues as secondary to such front-page concerns as fiscal policy, trade policy and national security. As a result, technology issues are not thoroughly considered in the formulation of national economic or defense policy. Furthermore, U.S. science and technology policy has yet to focus on the commercial challenge to American innovation. Federal R&D policies continue to emphasize national defense and basic research rather than activities that are more commercially relevant. Approximately two-thirds of the federal R&D budget is devoted to defense, and the nation continues to underinvest in the people, facilities and equipment that constitute its technology infrastructure.

Although the policy debate is still unfolding, some basic issues are emerging as widely shared concerns. Discussion revolves around four issues: 1)strengthening the American manufacturing base, 2)improving the U.S. policy-making machinery for technology, 3)upgrading the nation's technology infrastructure, and 4)encouraging wider national R&D efforts. Although individual programs have been created to address these needs, the necessary policy framework has yet to be fully developed, and there continues to be a gap between legislation and implementation of technology policy. These issues are discussed below.

1. Strengthening the U.S. manufacturing base

One issue on which there is wide consensus is the need to strengthen the U.S. manufacturing base. At one time, U.S. manufacturing was viewed as synonymous with moribund, mature industries that had more to do with America's industrial past than its high-tech future. This view has changed. Excellence in manufacturing is now generally recognized as essential to leading-edge technology firms as well as mature industries, not to mention national security.

In discussing manufacturing, two concerns immediately surface: the relatively high cost of capital in the United States and the pressure on American management for short-term results. The high cost of capital puts capital-intensive industries, such as manufacturing, in a difficult competitive position. It forces management in these industries to forgo investments with low yields, even if they are important to the long-term health of the enterprise. Furthermore, it means that the investments managers do make must either earn a higher return or a faster return than their foreign competitors, thus reinforcing the tendency toward short-term thinking. Although recent policy discussions have focused on such issues as the capital gains tax and depreciation schedules as a means of reducing the cost of capital, these initiatives fail to address the core issue -- low U.S. savings rates.

Record U.S. federal budget deficits -- averaging more than 4 percent of GNP in the 1980s -- have eroded the pool of national saving needed to finance investment in both human and physical capital. Net national saving in 1986 and 1987 stood at only 2 percent of the nation's gross national product, well below historical averages of approximately 7 percent of GNP. The by-product of low national saving, and the tight monetary policy that has been required to offset the massive fiscal stimulus, has been high real interest rates and low levels of investment. Net investment in the 1980s -- averaging 4.8 percent of GNP -- is significantly below historical post-war averages of 7.0 percent.

In addition to the cost of capital, the short-term bias of American management is a recurrent theme in policy discussions about U.S. manufacturing. In many ways, the discussion about short-term versus long-term is a discussion about the increasing tension between the U.S. financial sector and the U.S. manufacturing sector. Financial markets, faced with a broad array of international investment opportunities, are increasingly unwilling to make long-term investments in U.S. manufacturing when they can earn a higher return in a shorter time period by investing in Treasury bills or other financial instruments. Manufacturing, by contrast, requires long-term investment and patient capital. The discussion about short-term versus long-term thus mirrors the diverging perspectives of the U.S. financial and manufacturing sectors.

2. Improving the policy-making machinery

Another issue on which there is widespread agreement is the need to improve the U.S. policy-making machinery for technology.

Because public policy has not addressed the issue of the commercial application of technology, government policies often tend to impede rather than assist industrial efforts to bring new technology to market rapidly. No one agency of the federal government has broad responsibility for research and other activities related to civilian technology or for strategic coordination of technology policy at the national level. In the Executive Branch, responsibility for R&D is dispersed among 12 agencies. In Congress, the civilian science budget alone is divided among 9 of 13 different appropriations subcommittees, and there is no mechanism for devising reasonable compromises or setting priorities.

The problem is compounded by the lack of federal focus on technology's economic implications. Individual agencies are responsible for the research and technology that relate solely to their particular missions. Only the Department of Energy and the Department of Agriculture extend their focus to economic performance, and then only in specific sectors. The one organization that provides an overview of federal research and other activities related to economic performance is the White House Office of Science and Technology Policy (OSTP). The OSTP advises the President and helps coordinate federal R&D activities, but it has no line functions and a small budget, with staff mostly on temporary loan from other agencies.

The Department of Commerce also has a broader economic perspective, but its new technology programs are just beginning to take shape. The National Science Foundation also has a series of broader responsibilities. It supports education, research and information transfer in most scientific and engineering fields and, in effect, serves as the general science and engineering agency of the federal government. The NSF budget, however, accounts for only 2.5 percent of total government R&D funding.

The dispersed responsibility for technology apparent in the federal government is unusual among industrialized countries. Most national governments maintain a ministry of science and technology or a ministry of trade and industry that has broad responsibility for research and technology-related activities. Although there has been discussion of the creation of such an agency in the United States, so far little progress has been made.

3. Upgrading the technology infrastructure

The third area in which there is widespread consensus is the need to strengthen the education system, facilities and equipment that constitute the nation's technology infrastructure. While the federal government is being called on to assume a new role in some technology areas, there is a long tradition of government involvement in ensuring that the U.S. science and technology infrastructure is sound. Government programs contribute importantly to the education of scientists and engineers, the equipment and facilities, and the basic research that industry utilizes in its efforts to commercialize technology. Sustained investments in these areas are critical to the nation's economic future.

Although some recent initiatives highlight the importance of rebuilding the nation's technology infrastructure, these efforts continue to be hampered by a lack of funding. New Congressional fellowships have been established for American students interested in pursuing science and engineering education, and funds have been reallocated in the Department of Defense to enable more graduate students to pursue an education in these fields. But these efforts fall far short of the national need.

University research facilities face similar problems of neglect. Over the past two decades, while many foreign competitors have been aggressively building up their R&D infrastructure, U.S. federal funding for university research plant and facilities declined by over 90 percent in real terms. In a 1986 study on the health of U.S. colleges and universities, the White House Science Council estimated that a $10 billion program over the next ten years would be required to bring U.S. university research facilities to an adequate level.

4. Encouraging new national R&D efforts

The fourth area in which there is heightened interest and wide agreement is the need to forge new kinds of national R&D efforts. The most visible sign of this new commitment is the profusion of cooperative R&D ventures. Since the 1984 Cooperative Research Act was passed, over 140 cooperative research ventures have been launched in the United States. They have been complemented by a host of state technology programs that attempt to harness technological development for economic growth. Even the federal government has embarked on some new policies, such as the program to encourage technology transfer from the national labs to U.S. industry.

Although these new initiatives are important, it is important not to let their stated objectives overshadow the underlying dynamic at work. While these efforts are effective in generating concentrated, long-term funding and an excellent pool of talent, it remains uncertain what their ultimate contribution to industrial technology will be. It is unrealistic to expect new technology of vital interest and immediate relevance to industry to be developed rapidly as a result of these new cooperative relationships. Their primary importance is not creating state of the art technology that can be readily applied by industry, but building the new kinds of relationships among business, government and universities that are necessary to compete in an increasingly competitive international environment.

Conclusion

International competition has eroded the once commanding U.S. advantage in technology. In the process, it has caused a shift in U.S. business and government relationships and a reorientation of U.S. policy. Both the private and public sectors are increasingly concerned with a new set of technology issues related to international competitiveness and the commercial application of technology. This convergence of interests has forced both parties to rethink their traditional roles and to explore new cooperative relationships. As a result, a new U.S. public policy framework is emerging that focuses on technology and competitiveness.

Although the U.S. technology policy debate is still unfolding, the basic lesson is clear. The United States must recognize the new nature of international competition in technology and begin to develop national responses to the competitiveness issues facing U.S. industry. In short, the United States must learn to compete as a nation. U.S. science and technology policy can no longer be viewed as limited to basic research and military applications; it must also accommodate strategic economic concerns.

Senator GORE. Thank you for a really excellent statement.

I want to recognize the Senator from Nevada, Senator Bryan, first of all.

Senator BRYAN. Mr. Chairman, thank you very much. I need to go to another meeting, and I am sorry that I was not able to hear all of the panel, but I agree with you very much, Senator. That was an outstanding presentation.

A couple of questions, and if they have been commented on already, just point it out for the record so that we do not retrace the same path twice.

In talking with many people in the business community in middle-sized American cities—and I am not talking about the giants of industry—the myths, Mr. Burton, that you alluded to are accepted as gospel. There is really no great cause for concern for the reasons that you have outlined.

How do we effectively communicate that message to them? These are the people who are ultimately going to be devastated if these markets continue to be lost. How do we communicate the message to them without coming across as a doom and gloom prophet. Those of us who deal in the public policy realm hear a lot of this kind of thing. How do we get this message across to the business community, who would be the ones that would be most sensitive and concerned about this? Let me ask you to take a stab at that.

Mr. BURTON. That is a very difficult question, because I think what you are asking is how to get the message across constructively. We do not simply want to cause paranoia.

Senator **Bryan**. I agree with your premise. Having heard the Chairman comment so many times, I know that he agrees certainly essentially with the thrust of your testimony; but it is kind of like preaching to the choir here. We understand.

How do we get that out to the business community?

Mr. **Burton**. I think this chart demonstrates one way we have tried to do that. We felt the same lack of a handle. Everyone talks about problems, and what we tried to demonstrate was, in fact, there are a series of different kind of industries, different kind of technologies that we pioneered. We created the markets and owned those markets at one point, and we lost those very suddenly. In fact, the dollar figures are not insignificant.

Part of it is simply communication and discussion. The message really hits home in the pocketbook, however. There is an increasing discussion about manufacturing jobs versus service sector jobs, recognition that yet one more industry may go offshore.

The purchase of Columbia Pictures by Sony is an interesting case in point. When the question was posed, where are the other suitors for Columbia Pictures, the reason there were no more suitors is that Sony has a very wise, strategic reason for acquiring Columbia Pictures. They call it software for their hardware. There are not a lot of hardware industries like Sony in the United States anymore, and so we need to interpret signals like that in terms of their broader significance for the economy.

I have no magic answers for you.

Senator **Bryan**. The one that caught my attention in the past week is the restructuring of the tire industry and the dramatic changes that have occurred there, Uniroyal, Goodrich, Armstrong, General Tire. Now there are only three players in the international market. You have Bridgestone, which is Japanese; you have Michelin; and you have Goodyear. I guess you do not want to ignore Pirelli.

Restructuring is occurring at such a dramatic fashion for those of us who maybe are a little bit more exposed to it. I am not being pejorative of my constituents, but the tragedy that occurred in Texas with the bus and those children, that was a terrible tragedy. That is what dominates the front page. Everybody in your hometown saw that and grieves for the families. Certainly that is understandable.

Nobody really comes up to you and says, gee, did you see what happened in the tire industry yesterday. If you are in Akron, I am sure that there is a greater level of sophistication, but I think that is indicative of the kind of thing that you are talking about.

Mr. **Burton**. Let me make just one other comment and then turn it over to the other panelists.

First of all, I think part of getting that message across relates to those larger companies who are in international markets and live that reality every day, working with their suppliers, their compatriots back home to focus on that new reality.

Secondly, I think that in many ways, as this comment indicates, it is not a public policy or a Federal concern to get that message out. It is the private sector's responsibility. We at the Council have a major project under way where we are looking at the commercialization of technology not as a public policy issue but as a management issue; how to get technology into the marketplace more effectively. That is where we are getting beat in world markets—not R&D, not research. We are going to attempt again to bring that message to the business community, which is really what we have to do.

Senator **Bryan**. One last question, Mr. Chairman, and I certainly appreciate the courtesy extended to me on this.

Frequently when we hear from the various trade associations in American business, it is on issues that deal with minimum wage. You love it or you hate it. Typically, the trade associations are not much enamored with it. I am not debating the merits or demerits today.

You hear arguments about family leave. Most trade associations write this Senator saying we cannot have it. That family leave would be devastating. They talk about mandated health care benefits.

Are the trade associations, the folks that enlist all of these people who are out there in what I call Middle America, not the industrial giants, at their annual meetings, at their publication sources, newsletters, talking about the same thing that you and I and our Chairman are talking about this afternoon?

Clearly, the focus that I get from them is not on issues of competitiveness. They are talking about things that clearly affect them. Whether you are talking about capital gains or mandated benefits or family leave or minimum wage. These are legitimate policy issues which Congress has to address one way or another, but it almost seems as if those issues tend to obscure what in terms of long-term structural impact in the economy is going to ultimately determine our success or failure.

Yet, the business community with whom I have cultivated a close relationship over the years in a formal capacity working at the State level, seems to be more energized on these kinds of issues rather than talking about these long-term strategic concerns that you have addressed.

Mr. **Burton**. I think increasingly they are talking about competitiveness. The fact is we have had a very longstanding economic recovery, and in the face of that and in the face of declining unemployment rates and declining inflation rates it is difficult for many people who are not close to the issues to take them seriously.

Just as a side comment, one of our members asked us to do a major study on health care reform. It is costing the U.S. auto industry between $300 and $800 per car. They saw that as a competitive issue. So I think that there is a merging of some of these economic costs for industry that, on the one hand, are social issues and, on the other hand, are pocketbook competitiveness issues as well.

So many of issues are crossing boundaries and coming together.

Senator **Bryan**. Dr. Hill?

Dr. **Hill**. Senator, I could not help perking up. My first job out of graduate school as an engineer was in the central research laboratories of the Uniroyal Corporation. I recall going to weekly research review meetings in which my colleagues said we have a new tire design, and it is just a little bit not as good as Michelin's latest, and we are just a little bit behind Michelin. This was in 1969 or

1970. Michelin was setting the tone, and our guys were happy enough to be almost as good as Michelin.

I think one of the problems we have is that the lack of competitiveness sneaks up on you. We have all heard the story about what it is like to be a frog in a bucket of water over a fire. If you turn on the fire when the water is at 65 degrees and the frog is happy, he stays happy until he is cooked. That is where we are. We fall behind a little bit at a time.

Senator GORE. Let me finish the story. If you boiled the water first and dropped the frog in, he jumps out. Sputnik caused us to jump to a dramatic change in education policy.

The trends outlined in Mr. Burton's chart, while sudden in the context of the 20th Century, seem gradual in the context of the 1970s and 1980s. So like that frog, we just sit motionless as the problem reaches the boiling point.

Dr. HILL. You gentlemen are expert in figuring out how to get the water boiling, but it seems to me that one of the lessons from Sputnik is that there was a skillful use of the Sputnik event. The scientific reaction to the Sputnik event was not automatic. It was skillfully orchestrated by political leaders who had an agenda they wanted to achieve.

I have recently been reading a little book you may have seen by Akio Morita, the chairman of Sony, and Shintaro Ishihara, a recent candidate for Prime Minister of Japan. It is called "A Japan That Can Say No." There is plenty of fodder in that little book for heating the water. If you have not seen it, I will try to get a copy of it for you.

Senator GORE. There is also a book called "Yen, Japan's Financial Challenge to the United States", which recounts a late night conversation with some Japanese business executives including a principal officer of the Nomura Company, the one that handles so much of the U.S. debt, in which he was speculating wildly—I think fantasizing is the right word—about Japanese experts helping straighten out American financial policy and what concessions would come in return for that.

There are many things that Americans would be infuriated with here and which might make that neuroconnection and inspire a willingness to support dramatic responses here in the United States.

You know, some of us, Senator Bryan and I, certainly Senator Hollings, the Chairman of our full committee, and many of our colleagues have tried to get that message across.

Mr. Burton, I know that your group has certainly made efforts to say the water is boiling. I remember when Mr. Young's first report came out the report of the President's Commission on Industrial Competitiveness. John Young attempted to present the report to then President Reagan. I remember quite well that the Administration at that time would not even give a room for a press conference, having commissioned the group to conduct the study. The report was discomforting. This was a bipartisan group in every sense of the word.

I remember intervening to get a room so he could release his report for the press. This has been a few years ago.

The problem is that a message which conveys a sense of urgency is a message that makes people uncomfortable. If you fear the political consequences of making people uncomfortable enough to act, then the easiest response or seemingly the easiest response is just to keep quiet and not say anything and let the process continue.

There is almost a conspiracy in this generation against the future generation to say we do not want to face up to the changes that are necessary now. That we do not care that much about the consequences for the next generation. So we will foul the environment, we will run up the debt, forego the investments in education, and avoid the difficult steps to translate scientific research into useful changes in our economic strategy.

Russell Long, the former Senator who was chairman of our Finance Committee, used to have a saying. "Don't tax you, don't tax me, tax that fellow behind the tree." The fellow behind the tree is the next generation. That seems to me to be what we are doing.

I was very interested in your line of questioning, Senator Bryan. I read an article recently about the semiconductor manufacturing industry. You cited this, Mr. Burton, as one of your examples. It has come from a 100 percent U.S. share of American domestic market 1970 to 75 percent in 1987. That would have to be revised to sharply downward this year, would it not? What is it now?

Mr. BURTON. I am not quite sure.

Senator GORE. Perkins-Elmer is on the block; right?

Mr. BURTON. Yes. The figure that Robert Noyce from Sematech quoted was that in the last year 20 percent of the semiconductor the suppliers either closed or sold equity to foreign interests in order to keep open.

Senator GORE. Just in the last two months, though, two of the biggest companies in the United States have had serious negotiations of selling out to foreign purchasers. You know, that is getting right into the skeleton of America's high tech industry for the next decade.

Every one of these is worse in 1989 than in 1987, although some could not get any worse. You are down to 1 percent. I guess some of them have bottomed out.

Senator BRYAN. Mr. Chairman, if I may just make one other point here.

Senator GORE. Go ahead.

Senator BRYAN. When those of us go out to talk about this problem, to use your description, Mr. Chairman, it is uncomfortable. I think there is a different political climate today than there was in 1957 when Sputnik was launched, and the difference, I think is that there is a much greater skepticism about government.

I am sure that the scholars will say that the aftermath of Vietnam, and Watergate has made the federal government less credible, and since we are a part of the federal government, those of us that sit on the side of this table are less credible.

I cannot emphasize strongly enough the importance that I attach to what you are doing and to what all three of you have testified to. You have the credibility.

I mean, I have used this very chart, as I know Senator Gore has. Just this past August I spoke to a number of business groups and cited several of the examples. They did not have an idea that this was occurring.

I am not sure because I am perceived as a political figure whether there is a thought gee, I wonder if that Senator is really telling us the truth. I wonder what political ax he has to grind.

You folks enjoy a bipartisan aura which I think is important, and I think you have really got to help us make the case.

Doctor.

Dr. BORDOGNA. My mind is drifting around as you are talking about this because there is a real paradox here, and perhaps a hypocrisy because the very people that make up these trade associations, perhaps in these middle-sized towns, I see them a lot in a variety of ways.

One of my tasks as Dean is to march around the country to alumni associations to keep carrying the flag for Penn, and all over the place, the questions are the same everywhere.

One question is how do I position my child with the proper education to meet the competition of the future? And we have credibility. We talk about these things, and we suggest the thing to do.

So, these very people that are the middle line managers and so on of these small companies are asking the very questions that illustrate they know there is a problem. So, they know somehow.

But when they collectively get together, you are saying that they really do not do something about it at their level. But I get calls all the time from all over the place. I get calls from a lot of industrial people who have children, you asking, "Where should I send my child to school?" "What kind of education should he or she have?" And they know these things and they get them from us.

So, the problem is very deep. They do not seem to collectively feel frightened about it. But individually they are worried about their children. They thus do see the stress of international competition.

Senator BRYAN. And when the Chambers of Commerce talk to you about issues either during the course of your candidacy or afterwards, they are not talking, at least in most communities, about international competitiveness. That never comes up.

When you talk about it there is certainly interest, and I think there is concern, but I am just venting some of my frustrations with the three of you and wish you well on a very important mission for our country in a very real and meaningful sense. We will certainly try to do our part on this side of the table.

Thank you, Mr. Chairman.

Senator GORE. Let me read a quotation from the book that our witnesses referred to by Mr. Morita and Mr. Ishihara where they talk about the accuracy of American and Soviet ICBMs and how that accuracy depends on Japanese semiconductors.

Mr. Ishihara says, and I quote, "In some, if Japanese semiconductors are not used, this accuracy cannot be assured. It has come to the point that no matter how much they continue military expansion, if Japan stops selling them the chips, there would be nothing more they could do. If, for example, Japan sold chips to the Soviet Union and stopped selling them to the U.S., this would upset the entire military balance.

"Some Americans say that if Japan were thinking of doing that, it would be occupied. Certainly this is an age where things could come to that. The more technology advances, the more the U.S. and the Soviet Union will become dependent upon the initiative of the Japanese people."

And it goes on. But, you know, that is really not even the worst of it. We are used to thinking of national security in military metaphors. I mean, that is clear, and Sputnik required urgency, of course, because of its military implications.

But even if we manage to turn the corner where strategic warfare is concerned, military warfare is concerned, these trends are ominous in the commercial world and have implications for our ability as a nation to continue to enjoy the kind of life we have together with prosperity and peace and so forth.

And that is why I think it is appropriate for you on this panel to focus our attention on the new context in which U.S. science and technology policy must be viewed.

There are many changes that have taken place in that context, as I noted earlier today, but this one is one that the American people understand quite clearly. I mean, I think they understand it. They just do not feel they have been given leadership to enable them to rally round the obvious solutions for the problem, starting with education and then continuing through a more coherent policy on applied technology.

If you look at the figures on productivity, that is the key to economic success. We had steadily increasing productivity each year up roughly through the first oil crisis and since that time productivity increases have been nearly zero. The economists, after they sift through all of the data, tell us that the category that has made the difference is knowledge and the subcategories that are most important are one, education and, two, applied knowledge, the transformation of research into useful recipes for competitive improvements.

And so, if we look at the trade deficit and we look at America's relative slowdown compared to virtually all of our competitors, we have to acknowledge that science and technology policy broadly defined is the reason for it.

We are not educating our children. We are dead last among the major industrial countries today. Just comparing us to Japan, they go to school 260 days a year. We go 180 days a year. They have a 2 percent dropout rate. We have a 29 percent dropout rate.

They have homework. We have Nintendo, which we buy from them, and they treat their teachers like lawyers and doctors and we treat ours like baby-sitters. They are serious about it. We are not.

A teacher in Tennessee recently told me of an exercise where she got her ninth grade class to write letters to pen pals in a Japanese ninth grade class or the equivalent of ninth grade. These Japanese students not only learned science and technology, they learn English from the first grade on. She recognized after a few exchanges of letters that the letters coming from the Japanese students had perfect grammar, perfect spelling, perfect punctuation, some awkward colloquial phrases, but the letters going back in the other direction from the U.S. students were filled with poor spelling, poor grammar, poor punctuation and her comment was if they are doing better in English than we are, then really perhaps it is time to ask some tough questions about this.

And then where the second factor is concerned, our shortcomings in applied research are by now legendary and help to explain most of this chart. When you start the chart with the country that has pioneered a particular technology, you are talking about the country that has had the basic research and has discovered the basic technology.

And if you just go through this chart, it is obvious you have one right after another discovered in the United States and research and developed here, but turned into a useful device or useful technology by somebody else.

It is obvious that we have to have a much greater emphasis on that aspect of science and technology if we are going to be successful as a nation and for any academic researcher who instinctively feels that shift in emphasis might threaten the support for basic research.

I understand that sentiment, and I also understand full well how important it is to have an adequate robust funding level for basic research. The serendipity of science alone is a powerful argument for that, and we all understand that.

But the willingness of the American people to continue to support vast sums for basic research is threatened by a growing sense that in practical effect, we are creating the raw material for our competitors to exploit into products which they will then export to us. But the answer is not to stop creating the raw material. The answer is to start using the raw material and to start applying the knowledge and start educating our children and our work force so that they are capable of doing precisely that.

And if that involves changes in the balance of military and nonmilitary research, so be it. If it involves greater attention to the infrastructure of science, then obviously that will have to be a part of the answer.

I think this panel has really helped to focus those questions quite well.

I really enjoyed your statements, and we are going to continue these hearings, as I said, tomorrow and then in subsequent hearings including in a hearing later on where Dr. Bromley and his four nominees, designees, presidential nominees as his assistants will come and respond to the various issues that we have explored here today.

But for now, I would like to close by thanking members of this panel especially for staying for the afternoon session and thanking the witnesses in the morning session as well and all who have attended today.

We will reconvene tomorrow at 9:30. And, again, a word of thanks to these witnesses. We are standing adjourned.

[Whereupon, at 3:30 p.m., the subcommittee adjourned, subject to the call of the chair.]

NATIONAL SCIENCE AND TECHNOLOGY POLICY

FRIDAY, SEPTEMBER 29, 1989

U.S. Senate,
Committee on Commerce, Science, and Transportation,
Subcommittee on Science, Technology, and Space,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:30 a.m., in room SR-253, Russell Senate Office Building, Hon. Albert Gore, Jr. (chairman of the subcommittee) presiding.

OPENING STATEMENT BY SENATOR GORE

Senator Gore. The subcommittee will come to order. Good morning and welcome to the second of two subcommittee hearings on national science and technology policy.

Yesterday's hearing focused on the new national needs that we expect science and technology to help us meet, needs like economic competitiveness, maintaining strong military technology, training our children for the jobs of the future, and understanding and reducing the threat now faced by the global environment.

That hearing confirmed what many of us have suspected, namely, that these new challenges are urgent and important and national science and technology policy has only begun to respond to them. If we are to meet the challenges of the 1990s we will need to adapt our policies, our programs and our priorities to these changing circumstances.

This morning, in the second day of hearings, we will continue our examination of national science and technology policy by looking at emerging priorities and policies and by asking if the institutions which make and implement policies are well-equipped to handle new responsibilities.

We will look particularly at research universities, which perform much of the Nation's research and training, and at the Federal organizations which make and coordinate Federal policy, including the National Science Foundation and the White House Office of Science and Technology Policy.

I want to know what needs to be done and how best to do it and we have a very distinguished group of witnesses this morning to help us answer those questions. Erich Bloch, Director of the National Science Foundation, will start with an overview of the new institutional linkages among universities, industry and state governments.

Today, universities in particular are being asked to take on new responsibilities, including that of helping industry as well as conducting research and educating students.

Mr. Bloch, who has co-chaired a recent study of research universities, will discuss how able universities are to perform new tasks that are being assigned to them.

Then we will hear from three former science advisors: Dr. George Keyworth, Dr. Frank Press, Dr. Guy Stever. We are very pleased to have them, and they will discuss national priorities and the role of OSTP.

Dr. Press has given particular thought to the place of OSTP in Federal policymaking and has written about it.

Finally, we will hear from Dr. Herbert Simon, who is, of course, a Nobel Laureate and one of the Nation's most eminent experts on the relationship between science and government and the ways in which scientists and engineers can assist government. I look forward to hearing from all five of these distinguished experts who will help this subcommittee greatly in its continuing work to assess and shape national science and technology policy.

As I mentioned as yesterday's hearing, these two days of hearings are intended as a prelude to a continuing examination of this subject, both in overview and by focusing on particular elements of this policy. For example, in six to eight weeks we will have a hearing on the human genome project.

Then, not long from now—the timing is not up to us, but as soon as Dr. Bromley settles on the four individuals he will ask the President to nominate as his assistants, we intend to have all four of them here en bloc with Dr. Bromley to inquire about these matters and others.

The two days of hearings we are presently engaged in are intended, therefore, also to help us to lay a predicate for the questions that we will ask of those assistant science advisors in the confirmation hearings.

Now, let me recognize our ranking Republican, Senator Pressler.

Senator PRESSLER. Thank you very much, Mr. Chairman. I welcome the witnesses. I do not have an opening statement.

On behalf of Senator Kasten, I ask that a statement by the Council of Great Lakes Governors be included in this hearing.

Let me say that this statement I just received and I have been reading is very interesting. It is a statement by the Council of Great Lakes Governors calling for a more responsive Federal science agenda and the need for greater balance between support for electronics and advanced manufacturing technologies. It recounts what the Great Lakes States are doing and makes a number of recommendations.

Senator GORE. I might say, in yesterday's hearing we heard many references to the ways in which state governments are attempting to fill the void many feel has been created by the Federal absence from science and technology policy.

Senator Bryan?

Senator BRYAN. Thank you very much, Mr. Chairman. I do not have an opening statement but look forward to hearing from Mr. Bloch and the other witnesses.

Senator GORE. Well, thank you very much. Mr. Bloch is a personal friend as well as the Director of the National Science Foundation.

I enjoyed being with you at the South Pole when it was 56 degrees below zero, and talking about global warming in that environment was an interesting experience.

In any event, we are really delighted to have you here today, and please proceed.

STATEMENT OF HON. ERICH BLOCH, DIRECTOR, NATIONAL SCIENCE FOUNDATION

Mr. BLOCH. Thank you, Mr. Chairman, and I want to commend you and the committee for holding these very timely series of hearings.

Among the very many important and far-reaching problems that your invitation identified, I decided to focus on the university system. Our universities bear the major responsibility for producing the new knowledge and the technical work for us that are the basis of innovation and our economic competitiveness.

One of the major policy issues we face today is the need to maintain the health and vitality of the university education and research system.

The point of my testimony, Mr. Chairman, is that the university system is undergoing far-reaching changes and is moving into a period of serious strain.

Knowledge obtained through basic science and engineering research in universities in such areas as computers, electronics, new materials and communications has been the key to our international technological and economic leadership, national security and quality of life.

Two factors in particular have been responsible for the success of our university system over the years. One is the broad expansion of the system itself and increasing diversity of the university system over the last four decades. The other is the close relationship between research and education in our universities.

It is self-evident that universities the world over share similar responsibility in the education and training of students. The American university system, however, is unique in two respects.

One is the extent of its responsibility for producing the knowledge base that sustains our innovation and economic growth, and the other is its reliance on an apprenticeship system to produce successive generations of scientists and engineers.

In today's competitive world, knowledge is the new critical commodity, overshadowing the natural resources that we have been used to as looking at commodity items. Investment in the knowledge base and in the development of a high-quality scientific and technical work force is consequently a major instrument of competition for all nations.

As our competitors improved their economic performance after World War II, they are now challenging not just our economic leadership but our leadership in science and technology as well.

The consequences of their efforts are evident in a number of areas, including Japan's advances in supercomputer development, materials research, semiconductors and consumer electronics, to name a few.

Currently, Japan and Germany are spending the same percentage of their GNP on R&D as we do, but their rate of investment in research has been increasing more rapidly than ours. Their research investment is even more impressive when civilian R&D is considered alone.

We spend just under 2 percent of our GNP in this area, while Japan's rate is 2.8 percent. The combined spending of the European nations on civilian research is already 80 percent of ours, and it is reasonable to expect further increases as a result of regional integration and new linkages among the public and private sectors in academia.

This imbalance in our R&D budget between defense and civilian R&D has detrimental effects on our economic competitiveness. Another factor is that our civilian R&D spending is highly concentrated in medical and health research. Japan's is concentrated in materials and semiconductors and manufacturing research and robotics, computers, biotechnology, and many more areas.

In the years past, military research produced important spinoffs of the commercial civilian economy. Today, however, the improvements in military technology frequently depend on innovation in the civilian sector. It is a curious change of events. The technical electronic leading edge is no longer in the application to missiles or computers, but to consumer products.

Our universities must remain viable to be able to contribute to our international competitiveness, but universities appear to be entering into a decade of serious strains and difficult choices.

Let me focus on these items for a minute. Academia is the single most important performer of basic research, as you can see by looking at Figure 2, which is attached to my written testimony, a position that it acquired in the 1960s and occupies to this day.

Figure 3, furthermore, shows another thing, namely that since the early 1960s, close to 70 percent of academic R&D spending has been for basic research. Academic research funding leveled off during the 1970s, but it has resumed its upward trend in the 1980s.

However, despite dollar increases, the federal share of university R&D support has dropped from 60 percent to 1977 to 61 percent in 1987 with a commensurate increase in university and industry contributions and state contributions.

See Figure 5 attached to my written testimony.

Senator Gore. What is the other in Figure 2?

Mr. Bloch. The "All Other"?

Senator Gore. The category entitled "Other."

Mr. Bloch. That is income that universities get from sources like hospitals.

Senator Gore. No, it says by performer in the first graph. You have research in universities, you have industry performing research, and then you have the federal, which I take it the direct research activities by the national labs and so forth.

Mr. Bloch. Correct.

Senator Gore. And then you have "Other" which is larger than either the federal government or industry.

Mr. Bloch. That you are referring to Figure 2?

Senator Gore. Yes, the one on the left.

Mr. Bloch. There are a number of "others" in these other figures. In Figure 2 when you look at the distribution of research expenditures by performer, private consultants, Rand Corporation as an example of a private research institute, and things of this sort, are included.

This is really the source of the funds which is on some of the other chart, and it is from many sources. This is where it is being performed.

Senator Gore. All right. I do not want to belabor the point, but I am just astounded that we have a category that is larger than the federal government's share and larger than industry's share. It cannot be just institutions like the Rand Corporation, is it?

Mr. Bloch. It is pretty much. There are a lot of these institutions.

Senator Gore. So, most of that would be government-funded?

Mr. Bloch. Oh, yes.

Senator Gore. Just performed by private institutions with government funds?

Mr. Bloch. Correct.

Senator Gore. Okay, I understand now. Thank you.

Mr. Bloch. If you look at the source of funds, it is a different kind of story.

Senator Gore. I understand.

Mr. Bloch. In fact, you see that on Figure 5 when you look at the source of funding, the federal government provides about 60 percent of the total, with the other category being a very small amount.

Senator Gore. Industry is awfully small.

Mr. Bloch. Industry and academia is awfully small, but I must say that it has increased over the years.

Let me move on and say a couple of other things.

At the same time, despite a plateau in enrollments, academic expenditures are going up both as a total and on the basis of per unit cost.

One important factor in escalating university expenditure is the rising capital cost of maintaining and upgrading the infrastructure. By infrastructure I mean buildings, and I mean obviously equipment and other facilities. As equipment and instrumentation increase in sophistication and capability, they increase in cost as well.

Another reason is that the system is expanding because of the hiring of non-faculty researchers into the universities to do the basic research and other research that is being funded in those institutions. This puts pressure on income essentially.

An important characteristic of the research environment today is its increasing complexity, namely the growing significance of multi-disciplinary research and the development of new fields. In this environment, cooperation at the international level between industry and the universities and within universities has assumed a new importance.

Domestically this drive is expressing itself as bridge building among universities, industry and government. At a time of rising costs, cooperation promotes a more effective use of resources through the sharing of human and fiscal capital.

Cooperation is also an expression of the increasing congruence among the interests of university and industry. The contact between researchers of different sectors also serves as the single most effective vehicle in the transfer of knowledge and its eventual commercial application.

The importance of such direct contacts has increased as the time between the discovery of new knowledge through basic research and its application has diminished and because of such programs as the presidential young investigator program, the ERCs (Engineering Research Centers) and the SBIR program.

At the same time, however, these new cooperative efforts and linkages bring with it changes in established procedures and reward systems.

Another issue is the human resource issue. As a result of a decline in the college age population and its diminished interest in acquiring technical degrees, we may be faced with a reduction of the talent pool.

The numbers of foreign students has prevented the decline at the graduate level from being more dramatic than it is.

These foreign students fill important niches in our society and economy. Realism suggests, however, that as new employment opportunities emerge in their countries of origin, they will increasingly be tempted to go home.

The whole nation stands to lose if we do not succeed in attracting more of our own students, particularly women and minorities to the sciences and engineering.

What are the implications of these very diverse pressures and problems, the pressures on human resource shortages, the multidisciplinary research and the new linkages, the expenditures that are increasing and the enrollments that are flattening?

First, universities will have to play strategically and to think carefully about priorities if they are to avoid serious damage and dislocation in the long run.

They have become capital-intensive operations. Yet, as the current facilities problem illustrates, they have been late in facing up to the long-term requirements of managing capital investments.

Second, universities will have to take special care to preserve the core values that in the past have accounted for their excellence in science and engineering research and education.

The openness of our university research system has been an important factor in its effectiveness. Entrepreneurial activity by faculty resulting in constraints or delays in sharing research results could cause harm.

Another potential problem is the temptation to relegate teaching to a secondary status, second to research. To the extent that universities reinforce this tendency by rewarding research over teaching, they will affect the availability of their own and the nation's most previous resource, its human talent base.

Becoming aware of and managing institutional change is another important task facing universities. The introduction of new organizations and cooperative relationships will require vigilance to ensure that new demands are not met primarily through bureaucratic growth or the erosion of the academic research environment.

The long-term trends I discussed earlier have some implications for government as well. Because of its dominant role in funding university research, continued federal commitment to a national policy of investment in university basic research is critical to the vitality of both research and education in the university setting.

The pattern of federal funding is another important factor. Today 50 percent of all federal funding for university basic research comes from NIH and is targeted at the light sciences.

At the same time, DOD support for basic research has declined dramatically with the result that the National Science Foundation, with a small budget, has moved into the position of playing an increasingly central role.

Since our ability to address some of our most pressing economic problems depends on the knowledge produced in the physical sciences and engineering, we have to continue to examine the allocation of our investments.

Federal policies that encourage a stable planning environment will enhance the ability of universities to make an effective use of available resources.

An important step in this regard is the approval of the five-year authorization for NSF, improving the foundation's ability to pursue long-term programmatic goals.

The federal science policy process is another important issue. The dominant concern of our times is that we must use our available resources more effectively.

There is broad agreement that a coherent policy and budget process is the key to improvements in this respect, and this administration has made important contributions to this purpose. These have included the decision to elevate the position of the science advisor and the creation of a more effective science policy process in the White House.

Similar initiatives are needed on the part of Congress to streamline the policy and budget process in the legislative arena.

Congress needs to have a better understanding of the total range of needs and opportunities that face the research system so that priority decisions and tradeoffs can be made between the various components of the R&D budget.

Senator GORE. Are you saying there are some problems with our budget process in Congress?

Mr. BLOCH. Yes, I am saying that.

Senator GORE. I am shocked.

I see these reporters writing furiously—excuse me, go ahead.

Mr. BLOCH. Let me summarize.

The next decade promises to be a crucial one for the university research enterprise, especially in this time of budgetary stringency.

It will be important that the country maintains its commitment to university basic research and provide adequate support to science and engineering research and education as the means to meeting the challenges to the future.

The administration and Congress must be in a position to prioritize and make tradeoffs within the federal R&D budget.

At the same time, universities must adjust to the constrained fiscal climate and their evolving role in relationship to national needs.

Inevitably they will be faced with painful choices regarding programs and facilities and the affordability of the total system.

Thank you very much.

[The statement follows:]

Erich Bloch
Director
National Science Foundation
Testimony before the
Senate Committee on Commerce, Science,
and Transportation
Subcommittee on Science, Technology, and Space
September 29, 1989

Mr. Chairman, it is a pleasure to testify before this Committee on some of the important issues we are facing in science and technology policy today. I commend the Committee for holding this timely series of hearings and am honored to be a part of them.

These hearings reflect the fact that science and technology have assumed a central place among national priorities and that the research enterprise in this country is fundamental to our economic and technological leadership, to our national security, and to our health and quality of life. Providing adequate support to our research enterprise has been a priority of the last two Administrations and of Congress. This Committee in particular has been strongly committed to maintaining the health of the research enterprise, and particularly to supporting basic research at our universities.

Our universities bear the major responsibility for generating new knowledge and producing the technical work force that are the basis of innovation. Consequently, the ability of our research enterprise to contribute effectively to national goals in the future will depend on the health of the university research system. Among the major science policy issues we face today, one of the most critical is that the university system is moving into a period of strain as a result of changes in research, the emergence of a environment of fiscal constraint, and demographic changes that affect the supply of scientists and engineers.

These points will be the focus of my testimony today, Mr. Chairman. After discussing how the role of the university has been changing, I want to draw your attention to some emerging problems. Some thoughts on what responses this situation will require from all of us will conclude my remarks.

The role of the University

Knowledge obtained through basic research in the sciences and engineering in such areas as computer development, electronics, development of new materials, and communications has been a key to our international technological and economic leadership. It has been the basis of major advances in our understanding and treatment of health problems, and it has strengthened our national defense and helped us explore space. Almost every facet of life today, in fact, has been touched by the explosion of knowledge. Much of this basic research is performed in our universities.

Our universities have always played an important role in the development of an educated workforce and in the generation of a knowledge base that has supported a broadening range of economic and social activity. Following World War II, however, this dual mission of the university system assumed an unprecedented importance, largely because of the growing value of science and engineering research to our industrial base and its responsiveness to society's needs and desires. The decision of the Federal government that supporting science and engineering research and education is in the national interest resulted in a major expansion of Federal support for basic research at universities after the war.

Two factors in particular have been responsible for the success of our university system over the years. One is the broad expansion and increasing diversity of the university system over the last four decades, enabling it to contribute at a growing pace to the nation's social and economic development. (Figure 1) The other is the close relationship between research and education in our universities.

Universities the world over share similar responsibilities in the education and training of students. The American university system is unique in the extent of its responsibility for producing the knowledge base that sustains our innovation and economic growth and in the use of an apprenticeship system to develop successive generations of scientists and engineers.

The Growing Value of Knowledge

In recent years, science and engineering research has assumed a critical importance for economic competitiveness largely as a result of fundamental changes both in the world economy and in research itself. Today, the frame of reference is no longer national. It is global, and most goods we produce must now compete with merchandise from other countries as part of an expanding volume of world trade.

In today's competitive world, knowledge is the new critical commodity, overshadowing mineral ores, timber, and access to low cost labor. Unlike traditional commodities, like land or minerals, that are geographically rooted, knowledge can be produced anywhere. Knowledge diffuses quickly and easily, through human contact and communication. The rapidity with which this occurs is continually enhanced by improvements in communication and transportation -- surely some of the most visible and pervasive aspects of the technological revolution.

Investment in the knowledge base is consequently a major instrument of competition for all nations. The most important thing that a nation can do to assure its economic prosperity is to maintain its position at the frontiers of new knowledge by investing in science and engineering research and maintaining a high quality scientific and technical workforce.

As our competitors improved their economic performance and rebuilt their economies after World War II, they challenged not just our economic leadership, but our leadership in science and technology as well. The consequences of their efforts are evident in a number of areas, including Japan's advances in supercomputer development, materials research, and the highly competitive international climate in consumer electronics and high energy physics.

In this new competitive climate, U.S. spending for R&D, as a percentage of GNP, has increased very slowly, to about 2.8%. Currently, Japan and Germany are spending the same percentage of their GNP on R&D as we do, but their rate of investment in R&D has been increasing more rapidly than ours. The improvement in their research competence is even more impressive when civilian R&D is considered alone. We spend just under 2% of our GNP in this area, while Japan's rate is 2.8% and Germany's about 2.6%. The European community is another important point of comparison. The combined spending of the European nations on civilian research is already 80% of ours, and it is reasonable to expect further increases as a result of regional integration and new linkages among the public and private sectors and academia.

The level of civilian R&D funding has important consequences for innovation and commercial application. In years past, military research produced important spinoffs for the commercial civilian economy. Today, improvements in military technology frequently depend on innovation in the civilian sector. A strong defense posture will necessarily remain a national priority. But our sluggish productivity in the commercial civilian sector, and negative trade balances across major sectors -- traditional industry, high technology, and even services -- point to the need for continued focus on civilian research and technology, and a more effective use of our resources, especially our universities.

Universities and the Changing Research Environment

Our long term national competitiveness depends not only on adequate investment in science and engineering research and education, but on the ability of our institutions to adapt to changing needs and new challenges and to make an effective use of that investment. With respect to both requirements, universities appear to be entering into a decade of serious strains and difficult choices.

Funding and expense trends:

Long term Federal support of university basic research during the 1950's and 1960's has contributed to making academia the single most important performer of basic research, a position it occupies to this day. (Figure 2) Furthermore, since the early 1960's, close to 70% of academic R&D spending has been for basic research. (Figure 3) This represents a long term shift from the focus on applied research in the 1950's, when basic research accounted for about 40% of academic R&D.

Academic research funding levelled off during the 1970's, but has resumed its upward trend and the 1980's have been a time of growth in Federal support of basic research. Furthermore, two successive Administrations, with strong support from Congress, have committed themselves to doubling the Foundation budget by 1993. Nevertheless, the larger picture of university costs and expenditures contains several troubling elements.

Despite dollar increases, academic research support, as a percentage of GNP, (Figure 4) is levelling off, and the Federal share of all university R&D support dropped from 67% in 1977 to 61% in 1987. (Figure 5) The latest NSF data indicate that constant-dollar growth in non-Federal academic research and development averaged 7% per year between 1977 and 1987, compared to Federal support, which grew at the rate of 4% per year. Industry support, while still only 6% of the total, has been increasing 12% per year since 1977, and university support, the largest non-Federal source, has been growing at a rate of 9% during this same period. (Figure 6)

Against this background of overall slow growth and projected long term fiscal constraint, academic expenditures are going up sharply, both as a total, and on a per unit cost basis. (Figure 7) After levelling off in the 1970's, per capita academic R&D expenditures have climbed during the 1980's, and the capital share of expenditures, which had fallen to about 10% during the 1970's, has increased to nearly 15% in the 1980's, with slightly more than half going for laboratory space.

In the past, research expenditures grew in the context of rising enrollments. Today, that is no longer the case. (Figure 8) Enrollments have levelled off during the last decade. Furthermore, the greatest increases in expenditures have occurred at the doctoral universities, which have experienced the slowest enrollment growth. The highest growth of student enrollment since the mid 1970's has occurred in public two year institutions. (Figure 9)

Infrastructure:

One important factor in escalating university expenditures is the rising capital cost of maintaining and upgrading the infrastructure. As equipment and instrumentation increase in sophistication and capability, they increase in cost as well.

There is also considerable pressure on university resources resulting from long deferred maintenance and modernization of facilities. Facilities modernization is a very complex issue and I will not try to speculate on the various reasons why different universities defer facilities modernization. With respect to current activity, however, data from the recent NSF survey on university research facilities suggest that there is a great deal of construction underway, supported primarily by institutional and state funds.

According to the NSF survey, universities, state and local government, and industry, which also have a role and interest in this area, plan to spend over $3 billion for repair and renovation in 1988 and 1989. Universities also indicate that only a fraction of actual facilities modernization needs are being met. The facilities surveys have captured an overall picture of the current status of facilities. However, they do not assess the impact of facilities on the quality of research being conducted at academic institutions.

From the perspective of the Federal Government, it could be very disruptive to our national research enterprise to fund facilities at the expense of human resources and instrumentation needs. However, the Federal Government will continue to make infrastructure investments associated with highly meritorious research projects, particularly for infrastructure that represents "national capabilities" that go beyond the scope and resources of non-Federal groups.

Complexity:

An important characteristic of the research environment today is its increasing complexity. New fields are emerging and new approaches and instrumentation are making old problems more accessible, and multidisciplinary research is assuming a greater importance in pushing the frontiers of knowledge in areas such as biotechnology, information sciences, and materials research. In this environment, cooperation at the international level, between industry and universities, and within universities has assumed a new importance.

Internationally, it has drawn countries together in regional arrangements that encourage cooperation in research, technology development, and economic activities. For example, in preparing for 1992, Europe is mounting an impressive array of high technology research efforts that are bringing countries, and their universities and industries together. The continued development of the Pacific Rim will assemble a similar research and industrial power structure.

Domestically, this drive is expressing itself as bridge-building among universities, industries, and government. At a time of rising costs, cooperation promotes a more effective use of resources through the sharing of human and physical resources. However, the reasons for cooperation extend well beyond the economies that can be realized by sharing expensive research instrumentation or facilities. Cooperation is an expression of the increasing congruence among the interests of universities, industry, and government in a broadening agenda of research and education issues and enhances the creativity and productivity of the entire research enterprise. Also, the contact that results between researchers of different sectors serves as the single most effective vehicle in the transfer of knowledge and its eventual commercial application. The importance of such direct contacts has increased as the time between the discovery of new knowledge through basic research and its application has diminished.

In the last decade, there has been a growth in cooperative efforts and in linkages among researchers in universities, industry, and government. The Engineering Research Centers and Science and Technology Centers supported by NSF encourage such cooperation, and centers organized by state governments and by the universities themselves are becoming an increasingly common response to new challenges in research. However, the process of building these new linkages is recent, and the new institutional arrangements often create disruptions in established procedures and reward systems. They have also resulted in the creation of new organizational units alongside traditional departments.

The pressures to expand basic research are having an impact on the balance between the traditional university missions as well. Education at our universities will continue to be coupled with research. However, as the research function of universities expands against a background of level enrollments, and as research support becomes more comprehensive and the demands on the faculty researcher's time increase, the traditional close coupling of research and education often takes a back seat.

Human Resources:

We are faced with a decline in the college age population that will continue through the next decade. The contraction of the total talent pool is aggravated by a diminishing interest of students at all levels in the acquisition of technical degrees. Only the presence of large numbers of foreign students who have been drawn to this country by the excellence of our universities has prevented the decline at the graduate level from being more dramatic.

These foreign students fill important niches in our society and economy as university faculty members and researchers, teaching aids, and industrial research staff. Realism suggests, however, that as new employment opportunities emerge in their countries of origin, they will increasingly be tempted to go home. The drain of highly educated individuals would not only diminish the talent pool available to industry and academia.

Clearly, we must take up the challenge to attract more of our own students and to make better use of our underutilized resources, that is, women and minorities. These groups, together with new immigrants, will constitute 80% of new entrants into the labor market in another decade. The entire nation stands to lose if we do not motivate more American citizens to pursue technical careers. Within universities, however, because of an expected wave of faculty retirements in the mid and late 1990's, the negative impact of the declining talent pool will be felt earlier than in other sectors.

Implications for Universities

University Administration:

As a society, we are moving into a time of long term resource constraints requiring careful and effective use of resources. The implications for universities are the same as for the nation as a whole. They will be required to plan strategically and to think carefully about priorities if they are to avoid serious damage and dislocation in the long run. Universities have become capital intensive operations over the last generation. Yet, as the current facilities problem illustrates, they have been late in facing up to the long term requirements of managing capital investments.

Value System in Universities:

One of the most important tasks facing universities is the preservation and implementation of the core values that have served in the past to insure the excellence of our science and engineering research and education. The changing research environment, by stressing the appeal of some activities over others, can affect the reward system at universities, and result in an eventual erosion of their mission.

Entrepreneurial activity by faculty, resulting in constraints or delays in sharing research results is one example. Another is the temptation to relegate teaching to a secondary status, behind research. Undoubtedly, as enrollments stagnate but research activities grow and the pressures to acquire research support increase, the temptation to focus on what looks like a growth industry will be strong. However, to the extent that universities reinforce this tendency by rewarding research over teaching, they will affect the availability of their own and the Nation's most precious resource, its human talent base.

Institutional complexity:

Becoming aware of and managing institutional change is another important task facing universities. New relationships, organizations, networking, consortia, cooperation, are aspects of an increasingly complex research environment. Far from being a passing phenomenon, they are a sign of the changing times and a critical aspect of maintaining our competitiveness in both research and the global economy.

Universities have begun to adjust to this changing environment by supporting centers, multidisciplinary research activities, and cooperative efforts with industry. But the establishment of effective modes of operation will require vigilance to assure that new demands are not met primarily through bureaucratic growth and a deterioration of the academic research environment.

Implications for Government:

Overall support for basic research:

As the dominant source of funding for university basic research, the Federal Government exercises considerable influence on the general level and patterns of support. Continued Federal commitment to a national policy of investment in university basic research will therefore determine the health and vitality of the university system in both research and education. Federal funding in the last eight years has served to support such a policy, and it is in our national interest to maintain the momentum.

Patterns of Funding:

The substantial funding for basic research by Departments of Defense and Energy until the mid 1960's, together with growing NSF budgets, provided broad support for the physical sciences -- mathematics, physics, chemistry -- and engineering. (Figure 10) Today, 50% of all Federal funding for university basic research comes from NIH and is targeted at the life sciences. (Figure 11) At the same time, Department of Defense support for basic research has declined dramatically, with the result that the National Science Foundation, with a small budget, has moved into the position of playing an increasingly central role.

Research to support the Nation's health needs will obviously remain a major concern. However, our ability to address some of our most pressing economic problems depends on the knowledge produced through research in the physical sciences and engineering. Since our economic competitiveness will affect our ability to meet the full range of society's needs, we will have to continue to examine the allocation of investments in our research portfolio to insure that they are optimal.

Stability and predictability:

Stability and predictability are essential to judicious allocation of priorities. Federal policies that encourage a stable planning environment will enhance the ability of universities to make an effective use of available resources.

An important step in this regard is the approval of the five-year authorization for NSF, improving the Foundation's ability to pursue long term programmatic goals. NSF's emergence as a lead agency for important Administration initiatives in science and engineering research and education, including human resources, industry/ university cooperation, and the improvement of the research infrastructure at universities.

Budget and policy process:

The dominant concern of our times is that we must use our available resources more effectively and there is broad agreement that a coherent policy and budget process is a key to improvement in this respect. Over the last eight years, several initiatives of the Reagan and Bush Administrations, with Congressional support, have made important contributions to this purpose.

In keeping with his campaign commitment, President Bush has elevated the position of the Science Advisor to Cabinet rank and improved the effectiveness of the science policy process in the White House. For example, a recent White House initiatives on global change has resulted in the development of long term strategies to insure our leadership in this important area.

The effect of these changes will be cumulative, and will continue to generate improvements in the efficacy of the policy process in the Executive branch. Similar initiatives are needed on the part of Congress to streamline the policy and budget process in the legislative arena so that a better understanding is achieved of the total range of needs and opportunities that face us. Only in this context will we be able to make judicious choices about our priorities and how they should be addressed.

Conclusion

The next decade promises to be a crucial one for the university research enterprise. New demands from the evolving research environment, from the larger university community on the research system, escalating costs, and a climate of fiscal constraint are combining to produce multiple stresses. Especially in this time of budgetary stringency, it will be important to maintain our commitment to university basic research and provide adequate support to science and engineering research and education as a means to meeting the challenges of the future.

The last two Administrations have acted on the understanding that support for university basic research and education is an investment in the Nation's future that must be nurtured. A continuation of this policy is clearly in our national interest.

At the same time, universities must respond to the constrained fiscal climate and their evolving role in relationship to national needs with a more effective use of their resources and conscious policies to contain costs. Inevitably, they will be faced with painful choices regarding programs and facilities. A long term view of the strategic issues involved will be essential in helping them structure their priorities effectively.

FIGURE 1

Growth of U.S. Higher Education in the Twentieth Century and Major Socioeconomic Influences

As Measured by All Bachelor's and First Professional Degrees

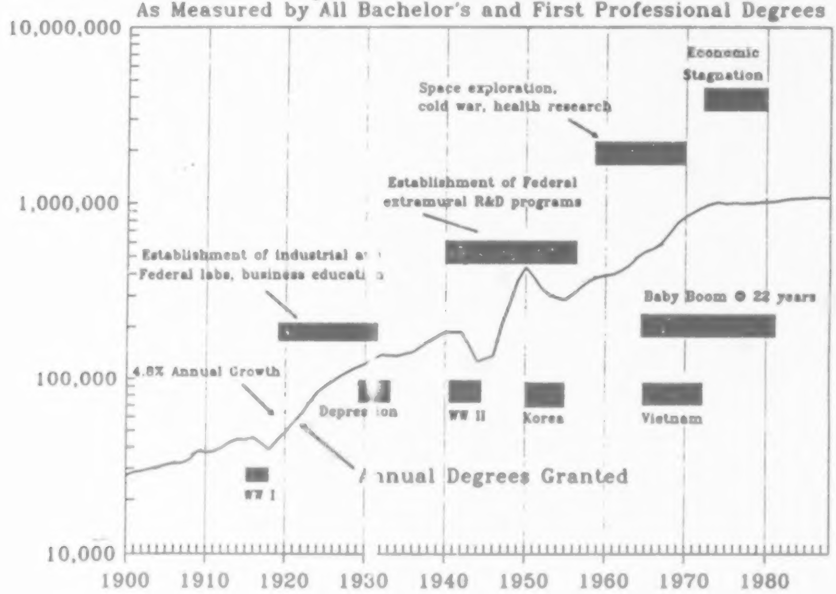
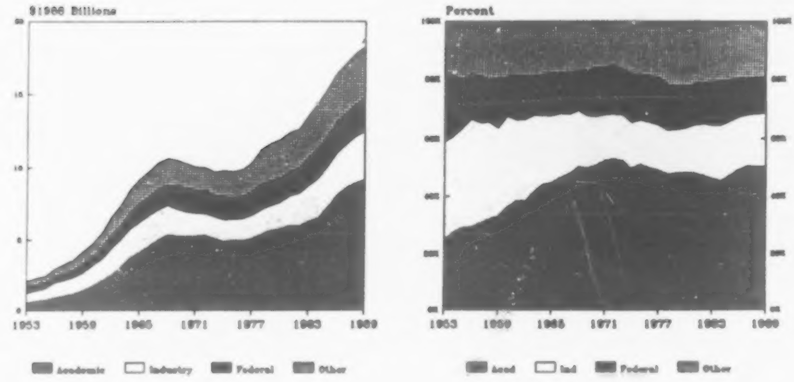


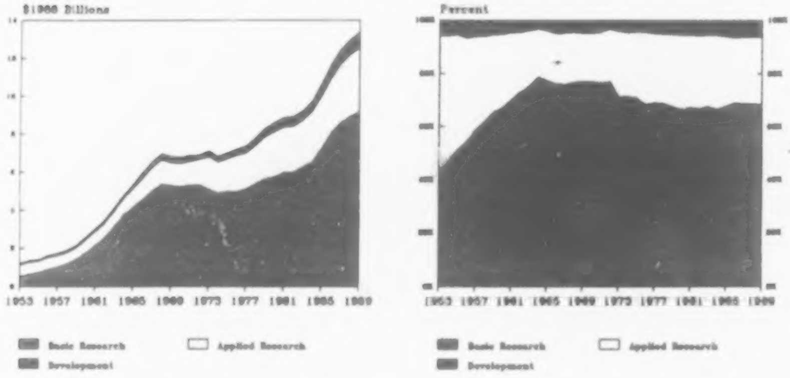
Figure 2



U.S. Basic Research Expenditures By Performer

Distribution Of U.S. Basic Research Expenditures By Performer

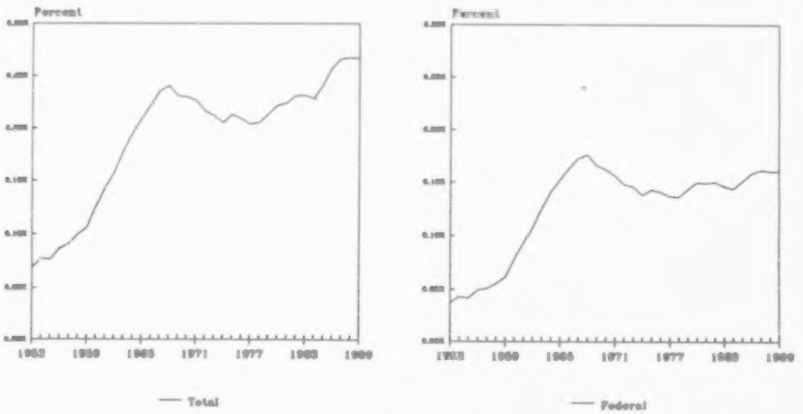
Figure 3



Academic Expenditures For Basic Research, Applied Research, And Development

Distribution Of Academic Expenditures For Basic Research, Applied Research, And Development

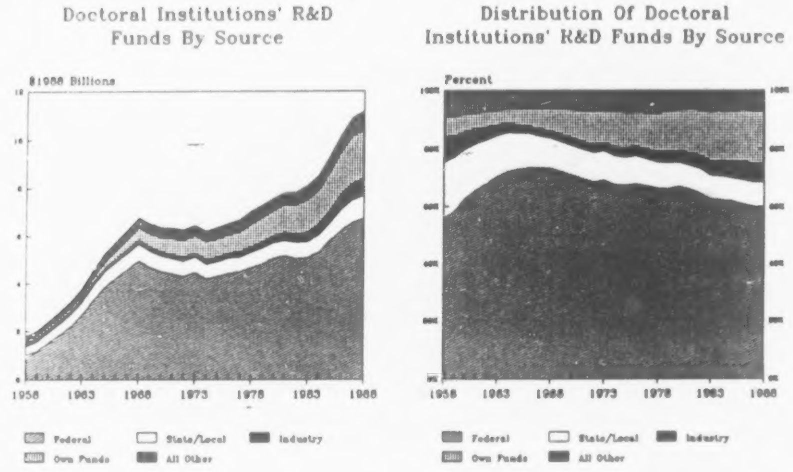
Figure 4



Total Academic R&D Funds As Percent of GNP

Federal Academic R&D Funds As Percent of GNP

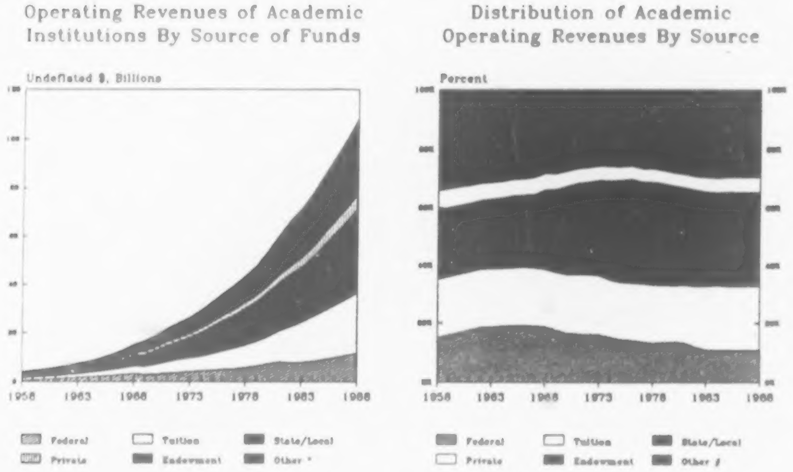
Figure 5



Doctoral Institutions' R&D Funds By Source

Distribution Of Doctoral Institutions' R&D Funds By Source

Figure 6



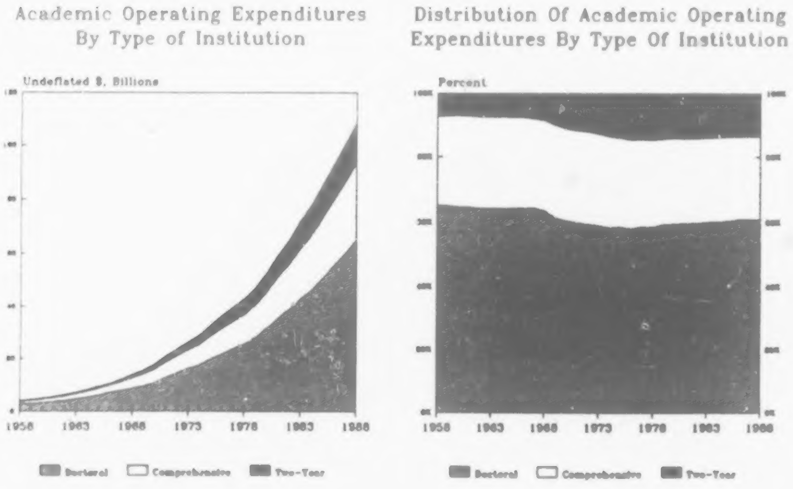
Operating Revenues of Academic Institutions By Source of Funds

Distribution of Academic Operating Revenues By Source

* Hospitals, Auxil. Enterprises, FFRDCs

Hospitals, Auxil. Enterprises, FFRDCs

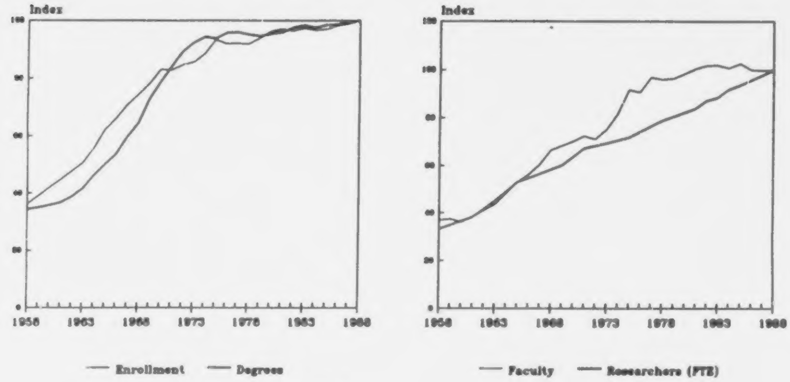
Figure 7



Academic Operating Expenditures By Type of Institution

Distribution Of Academic Operating Expenditures By Type Of Institution

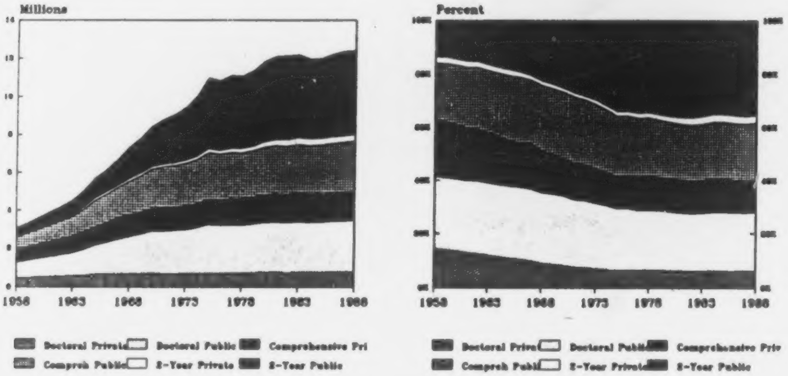
Figure 8



Doctoral Institutions' Enrollment And Degrees Indexes: 1988=100

Doctoral Institutions' Faculty And Researchers (FTE) Indexes: 1988=100

Figure 9



Total Higher Education Enrollment By Type And Control Of Institution

Share Of Total Higher Education Enrollment By Type And Control Of Institution

Figure 10

Postwar Changes in the Influence of Federal Agencies on U.S. Academic Research and Development

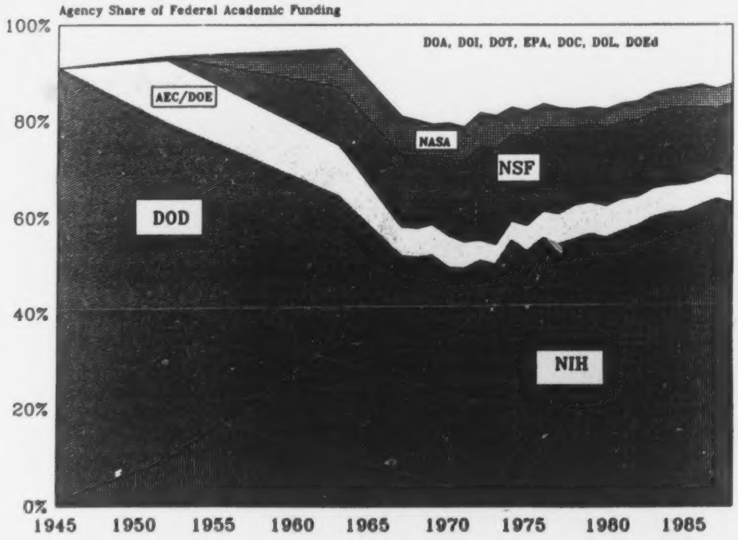
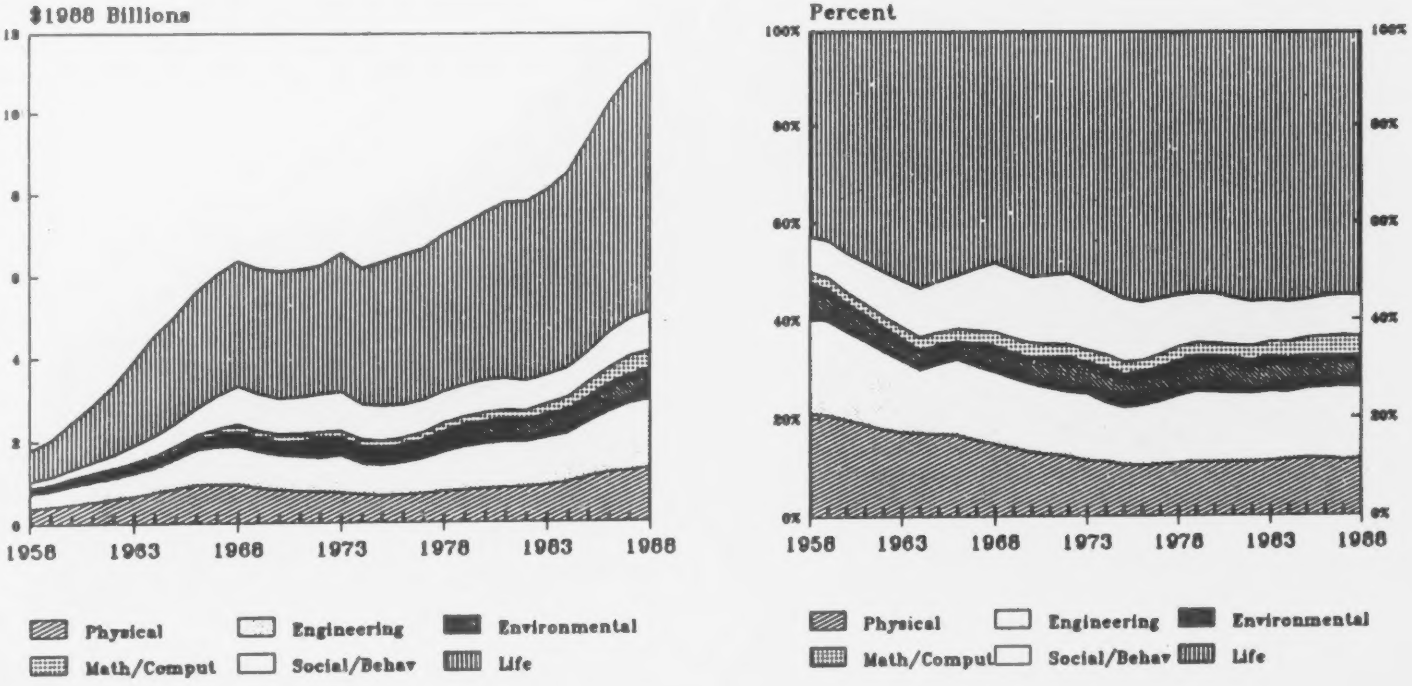


Figure 11



R&D Expenditures Of Doctoral Institutions By Science And Engineering Field

Distribution Of R&D Expenditures Of Doctoral Institutions By Science And Engineering Field

Senator GORE. Thank you very much. We really appreciate that statement.

You spent over 30 years with IBM before you came to NSF. And that experience has helped you develop a unique perspective as Director of the National Science Foundation. In fact, you helped to develop the modern mainframe computer. And you have essentially told us here today, among other things, that the new linkages that have developed between the various parts of America's science enterprise hold promise, but that problems are beginning to limit the ability of universities to handle some of the new challenges that we are looking for them to tackle.

Let me ask you about the capabilities of universities first. Can they support these new initiatives?

For example, are engineering research centers, other industry-university partnerships, and new efforts to spinoff academic inventions, making a significant contribution to competitiveness? Are they generally successful? Are the problems worse than the advantages? How do you view them?

Mr. BLOCH. Well, I view them, in balance, as a positive kind of development. If you look at the engineering research centers, last year, for instance, 50 percent of the funding for these centers did not come from the Federal Government; it came from industry, it came from states and some university funds, but primarily from industry.

Senator GORE. And foreign industry.

Mr. BLOCH. In some cases, foreign industry, that is correct.

Senator GORE. And in some cases you have foreign companies participating in institutions that have federal research dollars.

Mr. BLOCH. That is also correct.

Senator GORE. And arrangements which can give the foreign corporate entities priority access to the new knowledge thus created.

Mr. BLOCH. That is also correct.

Senator GORE. But does that make sense?

Mr. BLOCH. Let me put it in perspective.

First of all, it is up to the individual engineering research centers and their American companies to make a decision if they want to let foreign companies participate. They only let foreign companies participate where there is an advantage to whatever is being done, researched, developed, in that particular center.

Senator GORE. Well, now, that is a dressed up way of saying they only do it when they need the money.

Mr. BLOCH. No, that is not a dressed up—not at all.

Senator GORE. And when no American company is willing to meet the terms. I mean, American companies were not willing to develop the VCR, but foreign companies were. American companies have not been willing to enter into some of these imaginative relationships with universities for the same short-sighted reasons that they would not develop the VCR. And yet, for the same far-sighted reasons, a lot of foreign companies are more willing to participate.

The motives for accepting the participation of foreign companies may be complex, but surely an important part of the motivation is that they are willing to put up the money.

Mr. BLOCH. Well, I do not know of any case in any of the engineering research centers. I am not saying it does not exist outside—in fact, it does, and you know it very well—where there are not American companies that participate in that particular center, and therefore have a controlling kind of an influence on what the center is doing.

But we should also understand that the relationship between industry and the centers is not just to give money. That is one aspect of it, no doubt about it. It is also to bring some knowledge into the universities and to the table that is important for the development of that research.

And if that knowledge exists in Japanese companies, so be it. But we can benefit from it not just in the university, but also in the other industry companies that are participating in the engineering research centers by having that connection to, in that case, a foreign firm.

Senator GORE. Well, we heard in yesterday's hearing from Dr. Branscomb that the line between science and engineering is disappearing. And, of course, with your background and experience and present duties, you are probably better qualified than any person on Earth to address that particular question.

Assuming for a moment that Dr. Branscomb is right about that, then it is obvious that this nation and other nations concerned about economic competitiveness have begun to see the research enterprise in a new light.

The time between basic discovery and the marketing of a new product has been telescoped. And competitive advantage now comes, in significant part, from the ability to compress that time period, correct?

Mr. BLOCH. Correct.

Senator GORE. Well, this is an oversight hearing and is not designed to focus on foreign research activities. I had a chance to chair the first hearings held on this subject when I was chairman of a similar subcommittee on the House side quite a few years ago.

But the fact is some foreign companies have been quicker than American companies to see the commercial significance of basic research in particular areas, and have been more willing than some American companies to seek out innovative relationships with research institutions to advance the frontiers of science, yes. But they also get quicker priority access to new advances in basic research of the kind that has a likelihood of producing new way to be competitive in the world economy.

Now, if the United States Government, in assessing our science and technology policy, comes to that same conclusion, then we are going to have to look at these relationships between companies and universities a lot more carefully.

If one of our new objectives in spending federal R&D money is to assist the United States effort to be more competitive, then at some point I think there will be questions raised about intermingling federal R&D money with corporate funds from foreign companies in a way that gives our competitors priority access to basic research knowledge, useful in global competition, before American companies have access to it.

I mean do you not see that coming?

Mr. BLOCH. Well, let me answer that you really focused on more than one issue.

So let me focus on two or three of them.

First of all, with all due deference to Dr. Branscomb, and I think I know what he meant in a shorthand way by what he said, but I would have said it a little bit differently. I would have said today, the accelerated rate of the research development pushes engineering research and science research, many times, not always, much closer together than it ever was in the past.

That is certainly true.

Secondly, I would say that, in engineering, like in science, there are basic research questions. Too many people think engineering has nothing to do with research. False. It has as much to do with research as science has to do with research. There is such a thing as a basic research effort in engineering.

The third thing is, yes, this intermingling of foreign companies or potential intermingling with foreign companies, if it is a one-sided kind of a deal, I would agree with you, put up the barriers.

What we are insisting on today and what the foundation has been insisting on and the administration has been insisting is a quid pro quo. The access that foreign companies have to us should only be granted if we have access to their basic research.

Now, let me take Japan as an example, because it is always an example and it is always an irritant. We have been trying to open up the Japanese laboratories, with success, for American researchers. We have insisted that we can participate in the fifth-generation computer project, which you know very well is a high-prestige project in Japan, and that we have access to government laboratories there. The university laboratories are not that important, because they are not doing that much basic research, but the government laboratories do.

We have funding from the government of Japan to send researchers over. They are not just from universities, but also from government labs and private institutions.

And it seems to me that, in that area of basic research, and I am not saying that about development or anything else, we could gain and benefit if we had access to their increasing investment in basic research.

Senator GORE. Do you know of any instance where an American corporation has entered into an exclusive arrangement with a Japanese research institution? I mean the question answers itself—of course, they would not.

Mr. BLOCH. No, of course, not. But that is a separate kind of an issue, and we can discuss that.

I am just talking about in the normal state of affairs, research in universities, centers, or an individual's research and so forth; that we need to get access to their research, and be willing, by the way, to have access to their research. We have a hard time finding volunteers to go to Japan.

Senator GORE. Well, we have very few scientists and engineers that speak Japanese. The percentage is extremely small, compared to the very large percentage of Japanese scientists and engineers who speak English.

Mr. BLOCH. We fund Japanese language courses.

Senator GORE. Good.

Is anybody taking them?

Mr. **Bloch**. Yes, some people are taking them.

Senator **Gore**. Good. I did not want to interrupt.

Mr. **Bloch**. Well, that was my point, the quid pro quo. I think it is a mistake to close ourselves up, build a wall around ourselves, let nobody in and let nothing go out.

Senator **Gore**. Yes, I agree with that.

Mr. **Bloch**. Because a lot of research is done by exchanging information.

Senator **Gore**. I am not proposing that. There has been an impressive dialogue in the university community about this whole subject, and there are much greater sensitivities today than there were 10 years ago when the dialogue began. It is just that when you look at the details of some of these arrangements, you find provisions in some of these contracts, which I think would be offensive to the taxpayers who put up the federal research dollars, if the terms of the contracts were really laid out on the public record. Which I think they should be.

I mean it is a complex subject, but I really do think that it needs a little more attention.

Mr. **Bloch**. Let me just make one other point.

Industry, and American industry I am talking about now, today is a lot more aware of what universities can provide to them than they were in the past. And because of that, I hope that, in a natural kind of way, American industry participation in university research is also on the upswing. That was not the case five years ago.

Senator **Gore**. Well, very good. And this, let me say again, this is hardly the most significant issue we want to explore with you today. It is one of many. But I have taken time for my first round, and let me recognize Senator Pressler.

Senator **Pressler**. Let me ask a follow-up question in terms of are we spending our research dollars with universities wisely?

Now, I would guess that the Japanese are much more centralized; I do not know if that is true or not. We are all spread out, so to speak; maybe, in some ways, this is good. We are a big country, and we have diverse institutions.

But are we allocating our research dollars among the universities wisely?

Mr. **Bloch**. Well, I tried to focus on that subject during my remarks by essentially saying that we need to improve the allocation of our resources, which are limited and become more limited, in a more cohesive kind of a way than we allocated them in the past, when we were in an expanding kind of a system.

And it does not help if the whole R&D budget of the Federal Government, which is a large budget, by the way, is over $60 billion dollars distributed among nine or 10 appropriation bills, and tradeoffs are not being made between these bills.

And, as a consequence, I think there are certain areas that are not being treated the way they should be, and that is one of our shortcomings. So that is one thing.

The second thing is to the universities themselves. I look at the responsibility of the National Science Foundation to focus ourselves and to make sure that the country is at the forefront of basic research and basic technology. But, also, that we are broadening participation in this research effort, and in the education efforts, by all kinds of institutions that today are not participating to the fullest. And we have programs in place addressing that problem.

The EPSCOR program is one of them that really focuses on states, not so much institutions, but states and institutions within states that today are not fully participating.

We are focusing on the graduate institutions with special programs, because they are not fully participating, or not participating to the fullest in the way they could.

So I think we are trying to make that kind of a correction, and take that into consideration.

But you should understand that there is a tension there, between staying at the forefront of research, being the best in the world, and this broadening participation that I talked about.

Senator PRESSLER. Yes. Well, I guess I must say that—and I listened to your statement, because I have been struggling with this. I am very interested in the EPSCOR program, which helps some of the smaller universities get involved.

But are we too scattered out? I mean, do these other countries have one or two major research universities?

We have got the Ivy League, and then we have got the Mississippi Valley, and we have got California, and then we have Texas, and then we have the rest of the country.

And I am a great advocate of—I believe in small business; much of the innovation in this country has come from small business. But I hear from you that maybe we should have a more concentrated research effort.

Mr. BLOCH. Well, that is what I indicated before. I really think we need to come to grips with the problem. Can we afford the system that we have built up over a long period of time, where we have many universities do the same thing that other universities are doing, or do we need a more specialized way?

I do not know the answer to that, but it is an issue that I think needs to be looked at, and needs to be looked at very seriously.

Senator PRESSLER. Now what do some of the other countries that are leading in research do—for example, does Japan have a very concentrated system?

Mr. BLOCH. Well, the Japanese system, unfortunately, is quite different—or fortunately; I do not know how you want to look at it. It is quite different than ours—where basic research and education is much more separated than ours is.

Let me give you a better example, which is more akin to ours, and that is England. And England today is going through a major revision—by the way, I disagree with the way they are doing it—because fiscal constraints forces them into that.

And I hope that is not the case here, but I think we need to understand better what system we can afford in the future and how that system should look, and then move in that direction. It is not obvious what the answer is.

Senator PRESSLER. Now, we have been told repeatedly that the Federal budget is not large enough to cover all our national needs in university facilities, equipment and research.

You have previously stated that your first priority is to fund the research, and that facilities' improvement comes last.

How can the Federal Government encourage greater investment in our educational infrastructure by states, private entities and other groups to help meet that challenge?

I guess there are two parts to that question.

Is that true, that you feel strongly we should fund research first, and facilities' improvements come last?

Mr. Bloch. Well, I say it a little bit different; you can interpret it that way. I think we should fund people first, and brick and mortar come last. Yes.

Because I think, without people, you cannot do research. You can do research in crummy buildings; I have done it myself. But you cannot do it without people, and you cannot do it without instrumentation.

Since we cannot do everything, we are following that priority.

Senator Pressler. Yes. I am also worried that in our Foreign Service we are funding buildings and not people, but some would disagree with that.

So, you feel we are doing that, to some extent, in our science policy in the United States? Are the universities doing that?

Mr. Bloch. I am sorry?

Senator Pressler. Are the universities doing that—funding facilities before people in the scientific research?

Mr. Bloch. No, I am not saying that at all. In fact, I think if you look at the last few years, because of the policies of the Foundation, but not exclusively, buildings have deteriorated. No doubt about it.

But I am saying, in a constrained environment, you still have to keep your priorities what they should be.

Senator Pressler. Now, I know the National Science Foundation is trying to encourage more students to study science, math and engineering. But in our society, the thing to become is a lawyer or an investment banker, if you are going to be prosperous, the most prosperous.

And I understand that half of our engineering graduate students are from abroad and so forth.

Really, are we tilting at windmills, just encouraging people? The structure of our society seems to reward those who do not bother with the advanced science, math and engineering classes?

Mr. Bloch. Well, I think there is a lot of truth to that, and that is what we need to change. We need to turn our culture around.

But I do not think we are tilting at windmills, because many times, the individual would like to pursue a science or engineering career and cannot for a number of reasons.

Reason number one, he did not get the right education before he entered a college or a university—namely, in elementary school and in high school. And, therefore, he has no choice any longer to make that decision.

The second reason is that we are not supporting enough graduate fellowships, and we have been doubling those since a couple of years ago, but we are still not doing enough of that.

I also think we are not educating our students at the undergraduate level to the point where they are staying in engineering or in the sciences, and we could do a lot more to make that undergraduate education more effective, and also more attractive. It is not just effectiveness, but attractiveness.

And over the last few years, we have been turning our attention to that particular area. So it is a number of things.

And I do not think we are tilting at windmills. But you are right, the underlying culture, I think, has to change.

Senator PRESSLER. Thank you very much, Mr. Chairman.

Senator GORE. Thank you.

Senator Bryan.

Senator BRYAN. Thank you, Mr. Chairman.

Mr. Bloch, let me follow up on a question that Senator Pressler was asking, and that is, we all recognize there is a shortage of engineering and scientific and technical people at the university level. What is the appropriate role for the Federal Government to play in addressing that issue? And I presume that one of those areas was graduate fellowships, which you mentioned.

Is there anything else that we should be doing?

Mr. BLOCH. Sure. I think what we talked about this morning is very important. The Federal Government is a big supporter of the basic research that is going on, and needs to have a steady hand in the ups and downs. Being uncertain what tomorrow brings, I think, deters a lot of our students from pursuing careers in the sciences and pursuing faculty careers in universities. So a more steady hand is necessary.

Senator BRYAN. By a steady hand, you mean the level of funding, a predictability that——

Mr. BLOCH. Predictability.

Senator BRYAN [continuing]. It is not going to just be the fad this year to finance the program, and next year we will——

Mr. BLOCH. Do something else.

Senator BRYAN [continuing]. As changing vicissitudes of public opinion shift into another area.

Mr. BLOCH. That is exactly what I am saying.

Senator BRYAN. For those of us that are lay members in policymaking bodies like the Congress, it is very difficult when a group of scientists comes in and says: Look, the future lies in space; we ought to put our dollars there. And another group comes in and says: Look, superconductivity, we have got to get into that; that is a priority for us. And somebody else says: ceramics, that is the wave of the future, and on and on to the exotic technologies which are beyond the comprehension of at least of some of us on the committee.

What guidelines would you give to those of us that are policy makers? How do we establish the priorities? There is a basic premise that we should spend more for basic research, and I agree with your premise, but I think that you would agree that there is some finite limitation. We cannot do everything that we are asked to do.

You strike me as being a very practical man who would recognize that. What are the guidelines? What should the Congress be looking at in terms of ascertaining, what is the priority?

Mr. BLOCH. Well, I am tempted to say, Senator: Trust me.

But I will not quite say that.

The first thing I think Congress can do, is recognize that the foremost function of the Federal Government is the support of the infrastructure. It is the people and the equipment that is necessary, and that has to come first. And only after you are convinced that has been taken care of, the other problems should be addressed.

Senator BRYAN. How do you define the infrastructure? That is a term that we scatter across the landscape. I do not mean to be pejorative in the observation, but can you tell us what you are defining as infrastructure?

Mr. BLOCH. I know it is a misused term, and I should not use it. I mean by that, one, what we talked about before. Do we really attract enough people into the sciences and engineering? What do we have to do to attract more?

Our involvement in pre-college science and mathematics, and computer literacy, is certainly one good example.

The support of the laboratories that we have built up over a long period of time, so that they are at the forefront of their capabilities. And that means new equipment, renewed equipment, and so forth.

By infrastructure I also mean there are new technologies around: networking, computer, supercomputers, availability of work stations. Make sure that there are adequate means for that in the country as a whole, but in the universities, certainly, and in the government laboratories.

That there is an atmosphere where research is being pursued by industry and other actors.

The R&D tax credit is one of those things, making it easier for industry and universities to get together and come together on a common goal; anti-trust laws; and so forth.

I think all of these things—that is what I mean by an infrastructure.

And after that one is satisfied, comes the big programs: the space stations, and the SSE, and the human genome project and so forth.

But, I think, putting these large projects first, is missing the boat.

Senator BRYAN. I happen to agree. What you are saying is that laying the foundation, which isn't related to specific projects, should come first.

Mr. BLOCH. That is right, laying the foundation. You cannot build a space station unless you have engineers to build them with.

Senator BRYAN. Let me follow up.

I think all of us would recognize the shortage in terms of scientific personnel.

What can the Federal Government do? You are mentioning, and I happen to agree with you, that for all too many students the option is foreclosed if they get a poor education at the elementary and at the high school level. By the time they get to the college or university system, they simply do not have the tools to meet the academic requirements at the university level.

What can the Federal Government do to make sure that that precollege engineering and scientific base is present?

Mr. BLOCH. Well, unfortunately or fortunately—you can look at it both ways—our system of precollege education is a very diffused system. There are many actors in it, the localities, the states, and the Federal Government, and so it is not the Federal Government by itself that can solve the problem.

It has to solve it in conjunction with all the other actors, but certainly focusing on standards that were talked about over the last couple of days focusing on new material development and making sure that the material that we are teaching from and with is the right one and at the forefront of what can be done is certainly one area. Reeducating our teachers or educating our teachers in the first place, but reeducating them is very important because science is moving forward at a great rate.

And people become obsolete, not just teachers. People in industry become obsolete and government laboratories become obsolete, even in universities. So, it certainly can be a focal point to make sure that our students are getting as much exposure to what science and engineering is while they are in elementary and high school, and during summer months.

Last, but not least, some of the informal kind of education through museums and TV shows and so forth is one thing we can do.

The Federal Government by itself will not solve the problem. It has to work in conjunction with the states and work in conjunction with the localities. But I think we can be a catalyst.

Senator BRYAN. Mr. Bloch, let me skip into just another area for a moment if I may. Could you give us the guidelines as you see them for the Federal Government's participation with the private sector in developing certain projects where the capital requirements are so enormous that the private sector is disinclined to participate in that kind of risk without some federal participation.

We have heard some rhetoric and some slogans since I have served in this committee that we do not pick winners and losers. That does not give lot of guidance to many of us, very frankly, but we do, I think, need the benefit of your counsel.

You have spent years in the private sector. You now have a global view of what we need, and I find your testimony to be most helpful and very constructive in terms of assisting the subcommittee. But what should the guidelines be?

It would appear that the rest of the world, the industrial world, is participating in government-private sector projects, and if we do not do so, it would appear to me that we are not going to be able to compete in some of these capital-intensive areas.

Would you share with us your thoughts.

Mr. BLOCH. Yes, I would be glad to.

First of all, I think a no hands-on attitude by the Federal Government is the wrong approach. But, on the other hand, I must say that there is no general rule that you can apply to every situation.

I think what was done at SEMATEC, for instance, where the government and industry shared the expense, at least in the beginning certainly was the right thing to do for that particular problem, namely, the preservation of the semiconductor industry in this country because of its high defense interest and so forth.

That might not be the right thing for the next round. But let me also suggest another thing. The Federal Government should not do it alone. It has to do it together with industry.

If SEMATEC had not or if the companies that participated in SEMATEC would not put in 50 percent of the funding, I would say the government should not either.

So, I think it has to have a heavy involvement by industry. In fact, I believe that industry, not the government, has to be responsible for the execution.

HDTV is laying on the table right now, not because HDTV is important, but the consumer products, electronic consumer products area is important, and that is an entry into an industry that we have lost, and we have lost over the last 20 years.

What should the government participation be there?

I say the government should not participate until industry has a plan that is reasonable and rational and that makes sense. That plan has not emerged. And I think it is up to industry to make that plan. And so, what I am saying is hands off is not the right approach.

But, being on the forefront of it, government being the leader or the only participant is not right either, and for each case you should work out some kind of an arrangement between the private sector and the Federal Government with heavy emphasis on participation both financially as well as managerially of the private sector.

Senator BRYAN. Mr. Bloch, one last question. The chairman made reference to VCRs and how that technology was developed in this country. But its commercial production and distribution certainly is no longer part of our economic infrastructure to use an overused term.

Do you have any insights from what you have read, from what you have observed, about what went wrong there? What should we conclude if we are going to play a Monday morning quarterback role? What could the Federal Government have done? Did it fail in terms of assisting and working with the private sector or is this simply the failure of the private sector to translate a technology into a commercially marketable product?

Mr. BLOCH. Well, in that case I do not think you can blame the role on the Federal Government. I do not believe that. I think you have to look at the companies that were in that business at that time. They did not have persistence, the persistence that Japan has or had in pursuing a technology over 20 years or whatever it is and keeping it alive and working on it until it finally is ready for the marketplace.

My concern is the same concern I have on high temperature superconductivity, that we are going to do a lot of the research, but we are not going to have the persistence to stay with that problem because it will be 20 years before anything will come out of it.

We are much too short term, both as a government as well as a private industry. But, in that case, I would not blame the Federal Government.

Senator BRYAN. Mr. Bloch, thank you very much.

Mr. Chairman, thank you for your indulgence.

Senator GORE. Thank you. I certainly enjoyed those interchanges.

You say that in the VCR case the American companies did not show the persistence the Japanese companies did. I agree with that, but one reason they did not may have to do with federal policy, tax policy, antitrust policy. There are many areas that have been explored for answers to this dilemma, but it is really a systemic problem.

One economist uses an analogy to the Olympic games. He says why is it that the United States with 240 million people consistently wins fewer gold medals than East Germany with 17 million people?

And the answer is in part that East Germany uses methods that are inconsistent with our values and traditions. We do not like to pick pole vaulters in kindergarten and train them in a single-minded way and so forth.

But, if we decided it was important for us to win more gold medals in the Olympics, we still would not do what East Germany does, but we would be forced to examine our current approach to the Olympics, and we would be forced to recognize that we are not doing very well. We would be forced to recognize that the new approach taken by some other nations allows them to do a lot better at reaching that particular goal than we do.

Now, apparently, it is not very important we decide as a nation, to win gold medals at the Olympics because we are not doing that much about it that I see. But it is important for us to do well in international economic competition because our future standard of living depends on it. Our ability to finance the other goals of our society depends on our success in that competition.

It seems to me—and certainly there is nothing new about this—that the time has come for us to look very carefully at what it is that is so successful about the relationship in other countries between their corporate sector and their research sector.

If we make up our minds to compete more effectively, we still will not do what the Japanese do, but we will be forced to come up with some new approach that is consistent with our traditions and values and principles that is more effective than what we are doing now.

Let us take the case of HDTV. You brought that up just a moment ago. You said it is not important because of HDTV per se. It is important because of the consumer electronic products industry.

Now, what you mean by that, I take it, is that the economies of scale which will be gained by the nation which controls HDTV will give them a tremendous advantage in the production of the next generation DRAMs on which HDTVs will depend, and then the mastery of that generation of DRAMs will, in turn, give tremendous leverage over a whole new generation of consumer electronics that will replace much of what is sold in world commerce today. Is that what you mean?

Mr. Bloch. That is exactly what I meant, and also the fallout you get from that into other sectors like defense and so forth.

Senator Gore. Like air traffic control radar monitors, like cockpit displays in new jet fighter craft and new passenger planes? That is what you mean, right?

Mr. Bloch. That is exactly what I mean, but I do not mean by that that the Federal Government should be in a position where it designs the cabinet in which an HDTV set will go.

Senator Gore. What do you mean? What should we do?

Mr. **Bloch**. To make sure that the underpinnings are there, that we are funding the corporations and the activities and the research in the underlying technology.

Senator **Gore**. The basic research?

Mr. **Bloch**. No, not just basic research, but the capability to put a process plant in place, the capability to develop the tools that are needed.

Senator **Gore**. Wait a minute. Wait a minute. What are you saying? What should we do?

If we identify this as a clear priority for scientific and engineering research, and it is highly probable that the United States has a tremendous stake in doing well in this new endeavor, what should we do?

Mr. **Bloch**. Well, first of all, what we talked about before about basic research, put this aside for a minute. I am going to the next step. What should we do about HDTV in total?

What we should do is make sure that we have an industry in place or building an industry or help build an industry that is capable of producing HDTV, and that means making sure that we have the right instrumentation companies in place, that we have the right materials companies in place, that we have the right semiconductor companies in place that can feed that particular endeavor.

Senator **Gore**. We do not.

Mr. **Bloch**. That is exactly right.

Senator **Gore**. How are we going to do it?

Mr. **Bloch**. That is exactly my point. I think you have to depend upon industry to give you a blueprint of how to do that.

Senator **Gore**. They have done that. It has just been rejected by the administration.

Mr. **Bloch**. Well, I have looked at that. If you mean the AEA proposal, I would not put any money into that one either. It had much too little participation by industry in that particular proposal.

Senator **Gore**. Okay. So—but the response was not, hey, go back to the drawing boards, fill in some of the blank spots and provide a better plan from American industry. The response was we are washing our hands of this whole enterprise. You can forget it. We are not going to be involved.

Now, this was not your personal decision, but this is an example which you raised which I think does help to focus on the Federal Government's stake in science and technology policy. We have seen this administration make a choice to abdicate any federal role in this particular area.

It is not enough, with all due respect, to say well, the industry plan was not good enough because the response was not: Improve the plan. The response was: Forget it altogether.

Mr. **Bloch**. Well, Mr. Chairman, let me make one point, and I am probably way out on a limb when I make that point.

Senator **Gore**. Good. That is where we like to have you, Mr. Bloch.

Mr. **Bloch**. I am not so sure that is where I like to be, but let me make two points on this.

I participated in conversations over two years on SEMATEC. It took two and a half years from yea to nay and back and so forth to finally come up with a plan. Things are not being done overnight, not even in Washington.

The second point I want to make is the following. On HDTV, if the industry really would rally together and would come up with a sensible, rational, well thought through plan, I suspect that there would be another round of discussions.

Senator GORE. Well, I am sure there would be. There would be another round of discussions, but the decision from the administration would be the same, do you not think, really?

Mr. BLOCH. I would not want to predict that.

Senator GORE. Well, I would hope otherwise, but——

Mr. BLOCH. What came out of AEA, a billion and a half. You know, that is all there was in that report, and it took 60 pages to say that, and I do not think that is responsible.

Senator GORE. Well, I have legislation and Chairman Hollings has legislation which would, among other things, have the people with expertise in the government on this subject required to come up with such a plan in conversations with industry. And we have had trouble getting the administration to even support that.

But, again, this is not the principal subject of the hearing. It is a test case. It is a focal point, and you are well qualified to talk about it because in your earlier life with IBM you helped to create one of the first major consortia, the Semiconductor Research Corporation.

And I take it that leaving aside the AEA's proposal for HDTV, you do believe personally that we should have a national focused effort to ensure U.S. participation in the HDTV industry?

Mr. BLOCH. Absolutely.

Senator GORE. But you think we should wait for the industry to create it?

Mr. BLOCH. That is right, or come forward with a plan which involves the Federal Government. I have no problem with that if they come up with a rational and well-thought-through kind of a plan that is believable.

Senator GORE. Now, if you had to put a number on it, what percentage would you put on the probability that industry is going to do that?

Mr. BLOCH. A low number.

Senator GORE. Does that concern you?

Mr. BLOCH. Yes, it concerns me greatly.

Senator GORE. What should we do in response? This is science and technology policy, where the rubber meets the road, and we know the industry is not going to do it.

We know it is important to the country. We know that science and engineering represents the key. We know that the way it is being done today is completely inadequate to do what you believe is a high national priority, so what are we going to do about it? What should we do about it?

Mr. BLOCH. I think you have to focus on industry and the government together. Why do you not call them in together and sit them down and talk to them?

Senator GORE. Just have a discussion here?

Mr. **Bloch**. Well, you know, one makes progress through, as you know very well, and you know it better than anybody, through talking.

Senator **Bryan**. Mr. Chairman, would you yield for a follow-up on that?

Senator **Gore**. I am speechless.

Mr. **Bloch**. I did not mean it that way, you know very well.

Senator **Bryan**. Mr. Bloch, I appreciate your refreshing candor, I must say.

I must say we do not always find that quality in our witnesses, and you have been delightful this morning, whether we agree or disagree.

But I think the chairman makes a point. You say that we should ask the industry to come up with a blueprint. I do not disagree with that personally.

On the other hand, it seems to me if national interests are involved, and the long-term health of our economy, of our ability to compete for the rest of this century and the next, that there must be some leadership on the part of the Federal Government.

That leadership may not involve coming up with a funding package based upon the invoice sent to us by AEA, but it certainly ought to do what you are suggesting, and what I think the Chairman is trying to do, and that is to simply say at the Federal level to the industry: this is of such critical importance we expect you to come up with a plan and we assure you that if you do, and the plan is well thought out, that we will participate.

I think that is the kind of leadership at the Federal level from the Administration that the chairman made reference to.

Mr. **Bloch**. Let me just make two points. Both the former Secretary of Commerce and the present Secretary of Commerce had discussions with industry, and I was there on exactly this issue of HDTV, and in fact gave them, or urged them to come forward with a plan.

Moreover, Congress established a Committee on Semiconductors which is a permanent committee. I am an ex officio member of that committee. That is one of the issues that is being discussed in that committee, namely, coming forward with a proposal of what to do with, in that case the semiconductor industry, but it spills over into HDTV. It spills over into the other electronics products areas.

So I think there are things on the way, that there are discussions on the way, and I think Congress could weigh in on those also.

Senator **Gore**. If I could comment, there was a tragic story in "The Washington Post" yesterday, I believe, about the murder of a witness against a drug kingpin. A letter was mailed to the kingpin instead of the law enforcement authorities, and as a warning the witness was found with tape across her mouth. It was a tragedy.

Secretary Mosbacher looked to me like he had tape across his mouth the last time he came up here to talk about HDTV. Somebody sent to the White House indications of his comprehensive plan to do what you say is a national priority, and the White House put tape across his mouth, figuratively speaking, and said you cannot even talk to the Congress about what your true opinions are on the subject of HDTV.

So we are kind of talking around that particular subject. You can make progress by talking, and you can lose ground by talking, and it seems to me that Secretary Mosbacher decided to stop talking because the White House made a policy decision.

One of the things we heard from the first of our panels yesterday was that our current approach to science and technology policy emphasizes a completely decentralized nonpolicy in most cases, which has certain advantages and gives us as a Nation certain strengths. But they also said that the new context within which science and technology policy is now shaped ought to force us into a reexamination of that fundamental choice to a have a nonpolicy.

Just as in the example of East Germany and the Olympics, we are now confronted with a new model of government-business-university research in foreign lands, which is obviously far more successful in reaching certain objectives than the American model.

Now, to be fair in discussing this HDTV example, there has been some disagreement about whether it is too late for us to catch up, whether the Japanese have made the right gamble on HDTV, whether it might be seen as IITV, imperceptibly improved TV. And there have been other controversies, but it has been a focal point of this particular debate.

The key question is should the United States nonpolicy on science and technology, where targeting of specific, focused efforts is concerned, be changed to allow us to be more successful? You believe it should be changed.

You believe that we should take a different approach, and obviously you are not going to take on the White House head on. Of course, if you want to, we will be delighted to have you do that. But I understand your position. Do you have anything else to say on that? We are going to have to move on to the next panel.

Mr. BLOCH. Can I just comment on your last point, on the nonpolicy one? I would say it a little bit differently: that the coherence of our science policy is not very great and that we have to improve, rather than saying it is a nonpolicy.

Senator GORE. I think that is a better way of stating it, and in our next panel we will hear, for example, from Dr. Keyworth about the choice of SDI as a major focal point.

Where we are not willing to do it for something like HDTV in the commercial realm, we are willing to do it for SDI, and there are other examples.

There are, of course, many other questions we did not get to with you, Mr. Bloch. One, briefly. Global climate change is a subject where many of us believe the United States needs more focus and more coherence.

You and I were in Antarctica and we read a review of Antarctica research which said that even though Antarctica plays one of the most important roles of all as the engine of global weather, our scientific research efforts there designed to understand global climate change are not well-focused.

You are the lead agency there. What are you doing to change that?

Mr. BLOCH. Well, we have done quite a bit over the last year and a half. By the way, let me say one thing. The Federal Government has come together on that issue and you have seen that in the budget message that came up here last year, or this year, and I think that has brought the various agencies close together in coordinating the effort among ourselves.

As a consequence of that one, there has been a lot more of the budget that has been directed towards that end. For instance, in our 1990 budget request we have an increase in it of about 25 percent. We are about 30 percent of the total effort of the Federal Government in the total climate change program, and so I think you can be satisfied that that has been taken seriously and that more is being done today in a more coordinated way than before.

Senator GORE. Thank you very much. We certainly appreciate it, Mr. Bloch. We will be back in touch with you on a regular basis. Thank you.

Let me now call our panel of witnesses on Federal priorities in policymaking: Dr. Frank Press, President of the National Academy of Sciences, Dr. George Keyworth, Director of Research for the Hudson Institute, and Dr. Guyford Stever with the National Academy of Sciences.

If all three of you will make your way to the witness table, I would like to thank all of you for coming. You have busy schedules, and you have been very courteous to us in arranging an appearance here and we really appreciate it very, very much.

Dr. Press, we will begin with you. Thank you very much for coming. You and I had a conversation some time ago in advance of these hearings, and I have been very much looking forward to your presentation here today, so please proceed.

STATEMENT OF FRANK PRESS, PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Dr. PRESS. Thank you, Mr. Chairman. You know, the previous discussion was so comprehensive and illuminating that it will be very difficult not to go over the same ground and repeat ourselves. I would like to propose to you that you simply insert my testimony into the record and we save the time for discussion and dialogue, just as you had a few minutes ago.

Senator GORE. That will be fine. Why do you not summarize the key points you want to make and then we will use more of the time for the dialogue.

Dr. PRESS. I shall take not more than three or four minutes to do that.

Americans still dominate world science and technology. Any foreign observer would reinforce what I have just said. Large numbers of foreign students flock to our universities to study science and engineering and we still invest more in science and technology than any other country.

Why, then, is there a great deal of anxiety and stress in our technical community? Certainly, the budget deficit situation is forcing us to forego very important opportunities for lack of funding and fear that sooner or later we may cease to make essential investments in our future.

And there is concern about resource allocation, that we are not using the best of our limited resources.

There is concern about the probability that we will face a serious shortage of scientists and engineers, and about the quality of facilities and equipment.

Finally, there is the issue addressed in your previous discussion, the commercial application of science and technology in improving the economic future of the United States.

I want to comment briefly on the issue of allocation and establishing priorities. We at the Academies of Science and Engineering and the Institute of Medicine this past year suggested ways to improve that process of allocating Federal expenditures in science and technology.

We did that at the request of the Senate and House Budget Committees, and we are pleased that in the OMB and OSTP and in Congress our suggestions are the basis for discussion and have received a positive response.

We believe, of course, that the allocation of resources is basically a political decision and should be the purview of elected officials, but we proposed a sort of a template for analyzing a budget and establishing priorities.

For example, the science advisor, working closely with the OMB, should be involved very early in the budget process preparation of the letters that go out to the agencies with instructions for budget development. The science advisor, with access to the technical community, would know about the opportunities in science, some of the problems and bottlenecks, and use that as a basis for recommending to the President what his priorities might be for that particular budget year.

It might be maintaining the strength of American science in terms of people, training, education and the preparation of the future cohorts of scientists and engineers. It might be a facilities initiative, or an equipment initiative. It might be special problems that arise. Global environmental issues might now receive priority, or the AIDS crisis, or similar problems.

Certainly Congress would want to know what the budget does for any particular mission agency, how it supports the mission of that agency. Finally there is the issue of very large projects and why they should be initiated at any particular time, their impact on the rest of the budget. This might be a special criterion or area of examination in the preparation of the budget.

This framework is not very complicated and it makes common sense, but surprisingly the budget is not prepared that way, in a coordinated fashion across all agencies. Congress does not receive it that way and in any case disaggregates the S&T budget into many different Committees. There are ways of reducing that fragmentation.

The discussion that you had in the previous hour on our future ability as a Nation to compete I think deserves a great deal of attention. My colleagues here have certainly shared the experience of coming up to testify before Congress and being asked, "Why do we do all the research and create the new technologies for the Japanese to commercialize, export to the United States and reap all the profits?" Some people criticize one or another element of the research system—either universities, or industry, or government labs, or their reluctance to collaborate with one another.

But I think, and you hinted at this, Mr. Chairman, that our failure to use our scientific strengths and technological strengths more effectively in competition is due primarily to other factors the poor state of our education system, making our work force an impediment to product quality and product improvement; our failure to sustain investment in capital infrastructure in the areas of transportation, water supply, waste systems; and our low rate of national savings and relatively high cost of capital. If we do everything right in the whole process of innovation, but the cost of our capital exceeds that which the Japanese industry faces, then we will not be able to compete. It reinforces the system of management rewards and training that places low priority on investing for the longer term success of business firms. It took the Japanese more than a decade to develop our VCR technology to the point of being competitive. We did not have that staying power in this country.

And finally, the lack of integration of government, economic, technology and finance policy. These are the reasons, I believe, we are having trouble competing.

Well, let me conclude with that very brief summary of my prepared statement.

[The statement follows:]

TESTIMONY OF

FRANK PRESS, PRESIDENT
NATIONAL ACADEMY OF SCIENCES

Mr. Chairman: The United States continues to lead in science and in a great many areas of technology. Americans still dominate world scientific literature in most fields. They continue to record an impressive share of breakthroughs. Large numbers of foreign students flock to American universities to study science and engineering. And we invest more in science and technology than any other country.

This is not just scientists' perception of the facts. Most Americans see a strong scientific enterprise as essential to the creation of future wealth and national well-being, and they do so regardless of well-publicized allegations of fraud and assaults on laboratories using animals in research. They share your belief, Mr. Chairman, that

> ...America will not remain competitive without new ideas and inventions from our research laboratories. We will not find cures for cancer, heart disease, AIDS, and other diseases without continued strong support for biological research.... And we will not understand or deal with the threat of global warming and ozone depletion without a better understanding of the damage that man is doing to the planet....

More than ever, popular support is reflected in the attitudes of political leaders at all levels. The Administration and Congress acclaim the importance of science and advance one idea after another for new national initiatives -- a Sematech, a human genome project, a superconducting supercollider, a consortium to develop and produce high-definition television (HDTV), a supercomputer network, and so on. In the states, too, there has been a proliferation of scientific and technical programs, collectively representing an annual investment of some one-half billion dollars.

This ringing endorsement owes to an intuitive understanding that science pays enormous dividends. These have been calculated, at least roughly. The social rate of return on investment in fundamental research -- how much society receives in benefits -- has been estimated at 28 percent, an astounding yet conservative figure. And various analysts have concluded that technological innovation accounts for 44 to 77 percent of productivity increases.

So why is there so much anxiety? Why do so many scientists regard the system as under severe stress? The answer lies in underlying trends that threaten to sap the excellence of American science. That many of these issues are familiar does not negate their importance. They include concerns about

- total resources -- the certainty that budget deficits are forcing us to forego superb opportunities for lack of funding and the fear that sooner or later we may cease to make investments essential to our future;

- resource allocation -- the concern that we are not making the best of limited resources to maximize scientific productivity and fulfill national objectives;
- human resources -- the probability that we face a serious shortage of scientists and engineers, a result of poor preparation and inadequate recruitment of students;
- infrastructure -- the fact that in recent years we have skimped on research facilities and equipment in order to maintain support for people and activities; and
- commercial applications -- the fact that we often fail to use the new knowledge from our research institutions to compete successfully in commercial markets; indeed, frequently we find our competitors capitalizing on technology developed in the United States.

I shall comment on each of these in turn.

Financial Resources. A well-known observer of the science scene argues that "we don't need more money, only a better scheme for allocating it." Half true -- we need both. As for the level of total investment, the new resources required are surprisingly modest for the returns that can be expected. For example, of the total federal R&D budget of $64 billion, slightly more than $10 billion will go to basic science. If that investment were doubled for all agencies with science in their missions, as President Bush has proposed to do for the National Science Foundation, the added cost to the nation over five years would only be about $10 billion. I know that in many quarters that suggestion is viewed as unrealistic, but deficit reduction necessitates not only spending restraint but also a strategy to generate new wealth. Surely it is incumbent upon political leadership to find solutions to our budgetary problems without sacrificing investments essential to our future.

The issue of a more sensible allocation of resources has bedeviled both science and its patrons. As you know, the National Academy of Sciences together with the National Academy of Engineering and the Institute of Medicine this past year suggested ways to improve the processes of allocating federal expneitures on science and technology. Done at the behest of the budget committees in Congress, our report proposed a framework and procedures for a more rational approach to federal budgeting for S&T. Simply stated, we proposed that the budget should be prepared by the executive branch and justified to Congress within a framework of several elements:

- consideration of the adequacy of the aggregate support by all agencies for basic science and its infrastructure -- people, equipment, facilities -- "adequacy" being measured by the value attached to the opportunities gained or lost, the return to the nation, or the policies of other countries;

- consideration of the role of science and technology in serving national goals such as the competitiveness of American industry, attention to environmental contaminants, or dealing with the AIDS epidemic;
- examination of the extent to which agency S&T budgets adequately serve the missions of those agencies; and
- a careful assessment of the rationale for and impact on other efforts of large-scale S&T projects.

In addition to this framework for considering S&T budgets, we considered the process of budget preparation. In our judgment, the current decentralized process encourages reasonably thorough examination of the contributions of agency S&T programs to agency objectives. We did not propose to eliminate this pluralism. Nevertheless, we concluded that there is a need for improvements in the executive and congressional phases of budget preparation and review for those categories of activities that involve the contributions of several agencies and span the jurisdictions of several congressional committees.

Specifically, we proposed that early in the budget cycle the President provide agencies with guidance on selected crosscutting

S&T budget considerations and that this guidance be used throughout the cycle to weigh agency proposals in relation to the President's and Congress' priorities. For example, presidential guidance might emphasize support of graduate training in the physical sciences and engineering or the advancement of generic manufacturing technologies or research on global climate change or exploration of long-range applications of high-temperature superconductors. We recommended that this guidance be developed by OMB working closely with the President's Assistant for Science and Technology. We are gratified that Director Darman has endorsed this basic approach and taken steps to implement it in collaboration with OSTP.

The Pipeline for New Scientists and Engineers. Because it involves guesses about human behavior, it is difficult to predict future supply and demand for scientists; but we do know some things that ought to worry us. By almost any measure, precollege science and mathematics education is in trouble. Our students bring up the rear in most international comparisons of achievement. The decline in college enrollment due to the passage of the baby-boom cohort will likely result in fewer science gradcuates, especially if, as appears to be the case, science is attracting a smaller fraction of the brightest students.

It has been argued that "market forces" should determine student choices or that immigrants will fill the need. But I don't believe that we can rely on these sources. Rather, we need an extraordinary, coordinated response that deals with the deficits of science education, attacks the poor public image of science (the notion, for example, that physics is "dead, dull, and done only by white men"), and enables talented willing students to embark on careers in science.

Supplying the Tools. List the recent examples of breakthroughs in science, and you will inevitably find a new instrument -- usually a more sophisticated and considerably more expensive one -- the scanning tunneling microscope for visualizing atoms, the supercomputer for a variety of tasks, and various new tools for dechiphering DNA structure. My visits to university laboratories tell me that many of our best people lack essential pieces of modern equipment. The deterioration in university facilities is even more alarming. It is estimated last year by the NSF that for every $1 spent on needed repair and renovation, $3.60 was deferred.

To overcome two decades of neglect, particularly of laboratory construction and modernization, will require the combined efforts of all patrons of science -- public and private, federal and state, military and civilian. This can be accomplished if there are, for example

- o participation by all federal agencies with basic research programs;
- o a significant amount of local cost-sharing;
- o an increase in the facilities use charge in research grants to reflect real costs; and
- o no limits on debt-financing by nonprofit educational and research institutions.

The issue then becomes how to allocate funds fairly and productively, without creating entitlement programs for certain types of institutions or a pool of funds available for earmarking for particular institutions.

Applications. Those of us who regularly appear before congressional committees to discuss science and technology policy are familiar with the criticism, "We do all the research and create the new technologies -- for the Japanese to commercialize, export to the United States, and reap all the profits." Some criticize one or another element of the research system -- universities, industry, government labs -- or their reluctance to collaborate with one another. But I believe that our failure to use their results more effectively in competition for global markets is due primarily to other factors:

- o the poor state of our education system, making our workforce an impediment to product quality and productivity improvement;

- our failure to sustain investment in capital infrastructure, especially in transportation, water supply, and waste systems;
- the low rate of national savings and the relatively high cost of investment capital;
- a system of management rewards and training that places low priority on investing for the longer term success of business firms; and
- the lack of integration of government economic, technology and science policies.

Short of the President and his chief of staff, who recently remarked that science and technology are integral to "nearly every issue I touch," there is no single locus for integrating all of these issues and the policies that bear on their solution. But certainly the President's science adviser and, by extension, the Office of Science and Technology Policy can play a critical role in many of them. Last fall in a White Paper that we prepared for the new Administration we identified a variety of other presidential-level issues with critical scientific and technical components. They included

- major weapon system acquisitions and arms control measures;
- the decline of the defense industrial base;

- international collaboration and competition in science and technology, including terms of trade, cooperation, and access to research results and technological advances;
- means of alleviating or adapting to man-made changes in the global environment -- atmospheric warming, acid deposition, stratospheric ozone depletion, and loss of biological diversity; and
- responses to the AIDS epidemic.

Perhaps the most positive development in science policy in this Administration is the reinvigoration of the White House advisory function with the appointment of Allan Bromley to the appropriate rank of Assistant to the President. Dr. Bromley wisely views his mission as cutting across all of these issues -- international and domestic, budgetary and regulatory, civilian and military. He has breathed new life into the FCCSET mechanism for coordinating executive branch agencies. In particular, the Committee on Earth Sciences is a good example of interagency coordination with links to OMB that could be extended to other issues such as technology and competitiveness; agriculture, food and nutrition; and needs of the science and technology infrastructure. In addition, Dr. Bromley has begun to cultivate good working relationships with OMB, the agencies, Congress and its support agencies as well as the senior White House staff. And he has pressed, with some success, for the budget and staff resources necessary to do his job.

These steps are just the beginning, but they give us encouragement that the challenges to the continued success of American science and technology will be addressed and dealt with effectively.

Senator GORE. Well, that is great. An excellent summary. And we certainly appreciate it.

We are honored to have Dr. George Keyworth, II, with us, Director of Research at the Hudson Institute, and former science advisor. And we are grateful for your appearance here, Dr. Keyworth.

And if you wish to summarize, feel free; if you wish to present more of your statement, it is up to you. But your full statement will be put into the record and we would like to hear from you.

STATEMENT OF GEORGE A. KEYWORTH II, DIRECTOR OF RESEARCH, HUDSON INSTITUTE

Dr. KEYWORTH. Thank you very much, Mr. Chairman. It is a pleasure to be here today.

Let me attempt, to the best of my ability, read just some of the key parts of my testimony, if I may.

First, I agree with both Eric Bloch and Frank Press that the health of science in this country is reasonably well assured. In fact, the challenge before us is not science policy; it is technology policy. The science policy that we have today was basically that put in place by Vannevar Bush 40 years ago, and its wisdom, I think, places great honor upon him.

But technology policy is a very difficult thing. And the first thing we have to do is recognize that we do have a technology policy in place, but it is the wrong one. And let me offer a few examples, if I may, of what I mean by saying that we do have one.

Federal priorities for science and technology, as well as the means by which those priorities are set and carried out, have shifted in the past few years. But policies to match those priorities have lagged. At one time we thought it was sufficient policy to ensure strong support for science, particularly basic research. We did so, and we built the world's best science establishment. But the old assumption, that strong science would inevitably lead to strong technology, and hence to strong U.S. industry, has been proven to be inadequate today. We now have to develop and implement a science and technology policy for a time of unrelenting international competition. And in that area, OSTP will be obligated to explore new territory.

With some trepidation, I'll assert that the original concern, the health of science, is relatively well assured. My trepidation stems from the unarguable fact that there really are areas of underfunding in science, things we ought to be doing that we're not. And high on the list would be such things as improvement of research facilities in universitites and better incentives to attract and keep the best people in technical careers. But overall, we've come a long way since the 1970s, when the validity of science as a national investment had to be argued, and even oversold, year after year in the political realm.

That progress is not always appreciated, even by those who benefit most directly. There will always be strong pressures, especially from the academic community, for OSTP to focus its attention, and its limited opportunities to influence policy, on that old issue of the health of science. Without question, OSTP is the legitimate focus for that. OSTP, working the agencies and departments, can help organize and sort expert opinion on issues that the Administration is or should be working on. And, yes, OSTP plays an important role—sometimes as partner, often as adversary to OMB—in the annual allocation of resources as the budgets for R&D are put together. But there is an ever-present danger that OSTP will overemphasize and get hung up on its role as the intermediary between the science community and the White House.

I would offer an alternative for the late 1980s and beyond. OSTP should take a major role in developing, and stimulating, policies to improve U.S. technology, and in particular, to improve the climate for U.S. industrial technology. That, as I'm sure may colleagues on this panel will agree, is a much, much harder job to do. And I hope they would agree with me that it is increasingly important to try.

We recognize immediately that as OSTP ventures further into this realm it no longer plays the kind of singular role it plays in science policy. And by now it's catchup as well within the Executive Branch, with both Commerce and DARPA having moved quickly in the new Administration to take positions on industrial technology issues. But OSTP, precisely because it has little turf to protect, can, and should, take the lead for the White House in technology policy.

Where to start? That's a good question. It's not that the government doesn't have a technology policy, it's just that the policy was less planned than stumbled into.

Consider the nearly two-decade long isolation and alienation of universities and industry that basically was the result of government policy, even if that policy had the otherwise lofty objective of trying to assure the health of science through generous, often no-strings-attached funding.

But the consequence of that indirect policy was the increasing isolation of those two sectors, one from another.

Or consider the enormous talent pools that have preferentially grown in the national laboratories instead of in industry. That, too, was the result of government policy, and one that we are increasingly hard pressed to justify on the basis of current needs, but also very hard pressed to alter.

Or one more, the isolation from the commercial marketplace of large segments of our technical talent base because of the way defense technologies have been pursued. That, too, was the result of government policy.

Now, you can argue that I have chosen poor examples, since those were not intended results of those policies, but I would answer that, by default, those, nevertheless, are very much government policies.

My point, of course, is that many of the actions taken by government have led to a de facto technology policy.

What is the legitimate role of government?

That is a major portion of our continuing and ongoing debate.

Well, first, we must recognize that government is a customer, with only the most obvious area being defense. But government is truly a massive customer.

And second, government is and will doubtless continue to be a major development of technology in this country. So the question is how well we manage those roles of being a developer of technology and a major customer.

I would like to turn to an example that is very close to you, Mr. Chairman, of a particular issue that I think will be increasingly on our agenda in this issue of competitiveness and technology policy.

Now the international technology race is already underway for something that I call the digitization of telecommunications. In time, and not many years, in fact, this digitization will be the very center of the world's single largest industrial market. It is inevitable and it is driven by three streams of events, all flowing very, very swiftly right now.

One is the proliferation of what we call distributed processing. And that is nothing more and nothing less than the personal computer and all its variations.

Ten years ago there were only a handful of PCs in use. Today, in this country alone, there are some 40 million PCs. It has not only turned the computer industry on its ear, but it has also created unexpected and powerful demands for new products and services.

PCs are becoming an extremely potent market driver.

But a second force is the powerful technology that has grown up to enable computers to communicate with each other: the private networks used for airline reservations or electronic mail.

That technology, incidently, is a direct outgrowth of DARPA's work in the 1960s to set up a computer-based communications system to link researchers all over this country.

But the third force is advances in the technology of fiber optics, which will eventually take the place of conventional copper wires in ordinary installations to homes and offices.

Today we do have multiple means of communications entry into homes and offices. They may be twisted pair telephone wires, coaxial cables for television, terrestrial and satellite transmissions for broadcast signals, but even mail delivery, newspaper delivery and even the homework that children carry in from school.

But when communications become digital, we simply do not need all of those separate delivery systems. In the digital world that is coming, we can use the same pieces of equipment to move information around and display it, sending it from place to place over a common route.

And at some point in the future, most, if not all of those, the personal computer, the fax machine, the slide projector, the reference library, homework aids, telephone, television, and much, much more, will all be merged into one single system.

Of course, what that describes is a single system that integrates those three streams that flow separately now, PCs, telecommunications and fiber optics.

When we think about what such an integrated system would look like, then we are not surprised at the kind of attention that HDTV is receiving. If HDTV were no more than a better television, it would be much less important. But it is a mistake to look at HDTV as the real issue. As good as they are and as new as they are, they can be best described as the last, not the latest generation of TV.

What will follow after that will no longer be television, it will be digital communications.

Senator GORE. We have heard about the end of history, you are now telling us about the end of TV.

Dr. KEYWORTH. I am. The transformation of TV.

Senator GORE. Okay.

Dr. KEYWORTH. HDTV looks an awful lot like the successor to the TV and the personal computer, in fact, but combined. And it also looks like a likely candidate to become the focus for the entire integrated digitized system at some point in the future.

Our concern about it ought to be that it has the potential of being an unexpected form of competition for our own computer business and all that derives from it.

That is the competitive threat we have to respond to; not the relatively minor one of building better TVs. And that is the kind of new digitized technology that, in the long run, goes hand in hand with a fiber optic network.

As I said, such networks are simply inevitable. But what is not inevitable is that the United States will be among the leading players in this development.

And one thing seems certain, the country that leads, the ones that move quickly to establish national fiber optic telecommunication services will also be the ones to develop the ongoing technology that feeds into that system, and that hooks on to that system.

To be blunt, the Japanese are eager to install a next-generation telecommunications system. When they do, you can bet that they will waste no time in developing the hundreds of billions of dollars worth of consumer products that go along with that system.

I am convinced that this integration, this digitization, will become one of the major technological forces of the next decade or two.

Senator Gore, I note your own advocacy for what is called a national data highway, which is a fiber optic network connecting major supercomputer centers together. Yet there is no technical reason why we cannot simultaneously consider a comparable national data street system that will serve every home and office in the country.

Just a few years ago, before the explosion of PCs and fax machines, we could still look on this national network as something that would just come along in time. We no longer have that luxury, because the fiber optic network is rapidly emerging as the infrastructure of this new digital age, the information age, equivalent of the railroads or interstate highway systems.

Our continued delay will not only deprive our citizens of services that people in other countries are going to get, but worse, it will deprive our own industries of the opportunity to develop their products and services that will characterize this digitized world.

Now, my point: How does this become a technology policy issue?

Senator GORE. Hold on one second if you will. There are only four minutes remaining on the vote on the floor. Senator Bryan is on his way back and will start the hearing back up again when he arrives.

You have gotten into a subject near and dear to my heart, and I am grateful for it. And I want to get to the rest of your statement. But we are going to have to have a brief recess. Because Senator Bryan is on the way back, it may be no more than one or two minutes; I am going to ask him to crank it back up when he comes. But I will be back in about seven or eight minutes.

But, for the time being, with apologies for interrupting this excellent statement, we are going to stand in recess briefly.

[Recess.]

Senator BRYAN [presiding]. If we could reconvene the subcommittee hearing. Chairman Gore indicated that he will be back momentarily from his vote, and asked me to reconvene the panel, so we might continue with the testimony, I believe, of Dr. Keyworth, who was in the midst of his testimony.

We apologize for the inconvenience to the witnesses.

Dr. Keyworth, take your time to get refocused. We want to continue to hear your testimony.

Dr. KEYWORTH. Thank you very much. I will be, also, very brief.

Senator BRYAN. Take whatever time you need.

Dr. KEYWORTH. I have been talking about the importance of the national integrated digital network as the equivalent, in the information age, as highways and rail systems and telecommunications and electrification in our successful industrial age.

But how does this become a technology policy issue?

This is a case where government, because it sets standards and imposes regulations, exerts enormous control over the pace and direction of technology development. And in this case, the control is directed at the private sector in the form of today's telephone companies and cable and broadcast TV companies.

We are burdened, in this country, with a telecommunications regulatory system that is not only so complex that it defies reason, but worse, is rooted in outdated technological assumptions.

To be blunt, our existing policies reflect far more worry about protecting grandma's telephone service than about her grandchildren's jobs. No one except the government can sort this out at this particular stage.

And here is one case that cries for a fresh start, one that recognizes the technology that is spreading all around us, and one that recognizes the immense threat to our industrial future from those countries that are not so tied in political knots over technology policy.

My own experience in OSTP coincided with what I see in retrospect was the beginning of the rapid change and pressure caused by deteriorating U.S. positions in world markets. We could have been more aggressive ourselves in venturing into technology policy, but the signals were still pretty mixed about our national position and about the ways to respond.

I do think those signals are far clearer now, and we simply ought to be better able to respond.

That concludes my testimony.

Senator BRYAN. Doctor, we thank you very much and apologize for the interruption of your presentation. We will have some questions at the completion of the panel.

Dr. Stever, we would be delighted to hear your testimony.

STATEMENT OF H. GUYFORD STEVER, NATIONAL ACADEMY OF SCIENCES

Dr. STEVER. Thank you, Senator Bryan.

I, too, will do some summarizing. But let me say, first of all, that there is an oath that all former directors of the National Science Foundation and all former science advisers to the president take, written in blood: we will never disagree with one of our fellow mates in public. And I completely agree with everything said.

But as Dr. Keyworth was talking about this new communication system into the home, let me tell you that I arrived back at my home after just nine days away and found a pile of mail one foot high and three feet in diameter, and I tried to kindle that last night. I went to bed in a perturbed mood and during the night I woke up with a poem in mind. With apologies to Thomas Gray and his "Elegy in a Country Church Yard," I will read it.

Full many a bite of purest dots serene
The dark unfathomed reams of paper bare,
Full many a bite is born to blush unseen
And waste its greatness in the trash fire air.

I hope your system comes soon.

I will summarize the testimony, because I thought only of putting in my talk a few points for the new science and technology adviser.

In the first place, we all must rejoice in the information we are getting that the new administration is going to implement to its fullest the Science and Technology Policy Act of 1976. That was an excellent piece of legislation; it was pertinent then, today and in the future. And what we need is a full implementation.

However, with that full implementation, the science and technology adviser is going to be very busy as he sits on all of the various councils within the White House. And he has a very small staff. I think he is going to have a tough job to handle everything. The day-to-day problems will be enough to swamp him and his small staff, and I think we must seek ways to give him added help.

Certainly, we have got to be sympathetic to his request for people and money to carry out that important job.

Secondly, the balance in science and technology I think is an important responsibility for the science and technology adviser.

You know, I do not believe that any nation can really be a great nation in science and technology and get all of the benefits from science and technology unless it is very strong across the board, from basic science to applied science, to technology development, to engineering design, even to technical salesmanship and marketing. It certainly can use high technology in all of those, too.

And to ensure that balance is a very difficult thing in times of international competition, which we brought on ourselves, I think, by failures of government, business, financing, and individual consumers.

Nevertheless, I think we have to protect our basic research and, as some of the people already have pointed out, those parts of science which are producing the seed corn of the future.

The progress in basic science, by the way, depends so heavily on well-equipped and well-supported individual investigators and small groups of professors and students, and we must protect that.

But I have to point out also that there are some fields, like astronomy, oceanography, planetary geology and high energy physics and so on, where individual investigators depend on large and expensive facilities and/or logistic support systems, as the researchers at the South Pole depend upon, since our chairman spoke about the South Pole earlier.

I believe that we have to be pretty careful to make sure that we are not just picking our science priorities on the basis that they do not require big facilities and logistic support systems.

There are some fields of applied research which clearly promise us return, and all of the speakers before have talked about them—particularly the whole area of solid state analyses and all of the things in electronics and communications, that follow from it.

I agree completely that we have to concentrate heavily on the new ways of applying our science better. In some cases the best thing we can do is to facilitate industry's doing that job, provided they accept that responsibility. Get obstacles out of the way of industry. Give them encouragement via tax uncertanies, and some reduction regulation, and some retaxation of the laws preventing different companies from getting together.

We can do a lot of experimentation, and we ought to do that experimentation. There are already some signs of success, but let us not think that we are through the experimental time there.

And finally, on the environment. Our chairman mentioned that he and the Director of the National Science Foundation were at the South Pole together when they prayed for the greenhouse effect, because it was 56 below.

Well, I have to tell you, one of his more distant predecessors and I were at the South Pole and it was only 50 below, and so consequently, we already have a cooling.

Nevertheless, the problems of the environment are very serious, and we have to apply our science and technology there. And curiously enough, a large number of them are all wrapped up in energy, the environment and the economy. And I do not think that we have organized government well, either at the administrative level or the congressional levels, to handle that complex mixture, and we ought to start.

Finally, all the speakers have talked about science education. The one thing that puzzles me is that most scientists I know, and most engineers, and most academics talk about what a fine system we have at the college and post-graduate level if we only supported it in the universities. And they tsk, tsk at great length about the kindergarten through grade 12 education.

I think we are going to have to get our scientists much more thoroughly involved in the latter. Already there are some starts. I can think of various laboratories, especially in government but others as well, taking responsibility for a local school jurisdiction and helping them in science education.

New Jersey, I believe, and maybe some other states, have waived teacher training certificates for retired scientists and engineers. I think that is a very good way for increasing the supply of teachers and also getting people that know the field.

Now they also have to be very careful that they understand the psyche and the personality and the desires of young people. But maybe we can give them that in summer school education.

Finally, Mr. Chairman, we are rich in science, talent and facilities, and ideas abound for strengthening our science, engineering and technology. So many science fields show great promise, I do not think we dare waste our opportunities.

Indeed, it is our responsibility to seize them. And if you worry about our budgeting problems, our tight budgets, the best way to get out of them is to strengthen our science and technology so we are competitive in the world, so that our economy flourishes, so we do not have budget problems in science and technology.

Thank you very much.

[The statement follows:]

Testimony of Dr. H. Guyford Stever

Mr. Chairman and Members of the Committee:

It is an honor to testify to you on important issues facing us in science and technology--it's governance, administration, support, and application.

1. The Science and Technology Advisor to the President

The Science and Technology Policy Act of 1976--an excellent piece of legislation, pertinent then, today, and in the future--has been implemented in varying degrees and with various successes and shortfalls by the past three Administrations. The Bush Administration with strong, almost unanimous, advice from many scientific, engineering, academic, and industrial sources has promised to strengthen the implementation of that Act. The recently appointed and confirmed Science and Technology Advisor to the President has already been given exceptional appointments to the relevant units of the Executive Office of the President, and appears to have his voice heard; he receives frequent requests for participation and help on important matters with science and technology implications. This is gratifying, and we should rejoice. The Administration and the Congress must ensure that the Advisor is given the needed staff and funds to carry out his tasks. He cannot handle them alone or even with the help of his relative small staff; in fact, appointments to that staff are slow in getting through the appointment process. The short range, day-to-day problems will keep him and his small staff very busy; to handle the medium range problems, he will need added help to analyse and assess problems and solutions.

2. Balance in Science and Technology

Scientific and technological strengths are usually considered vital in the increased global competition for economic leadership. Our problems in the competition have been exacerbated by the financial problems brought on by our poor governmental control, questionable business practices, and excessive individual consumption. We in science and technology are expected to provide our contributions in a period of tight funding from the Federal Government which is struggling to balance budgets and pay off the banking and business excesses of the past. There are also problems in funding research and development by private industries some of which are struggling with excessive debt, while others are still accenting short term returns. The S&T strengths of overseas competitors continue to grow. Some of these pressures, together with the new globalization of the high tech industries, are resulting in the reduction of industrial support for research and development, and in the shifting of industrial R&D activities abroad.

I believe that governments, both federal and state, will be called on for greater support of S&T in the future, especially in those applied areas so important to our international competitive posture, lest our future competitive strength continue to weaken relative to overseas competition. We shall be called on to tighten our funding belts and engage in prioritization. Certainly the latter can yield some help. Clearly there are laboratories in which the missions have become less important, and/or the capabilities have seriously deteriorated. I believe that the White House and the Congress should carefully assess the actions of the Departments and Agencies in their current budget tightening activities, to ensure that those units with stengths survive and those without do not. Also we should develop anti-priority lists of those efforts which can be eliminated or cut back. Why should we, in budget tightening times, always seek to suppress new starts, many of which will keep us on the cutting edge, instead of knocking out some of the older, decaying programs? There have been some good studies of this area in the past which have not been implemented. In making choices in these areas, S&T should not be judged on a political or regional basis; rather some form of a peer review merit system should be employed. The National Research Council report to the Congress on setting priorities can be a good guide.

3. Basic Research

In my view, no nation can be considered a leader in science and technology unless it has strengths in the entire spectrum of activities ranging from basic science through applied science, technology development, engineering, and production to marketing of products and processes. We have those strengths, but to maintain a balance across that spectrum requires constant vigilance of our leaders; government leaders particularly have immense powers to change all components of the spectrum. Making judgements on this balance and involving other leaders in such judgements may be the most important service that the President's Science and Technology Advisor can perform for the Nation.

The support of basic research is often considered fragile in tight budget times. We must protect it at all times. There are those who say that in this time of international competitive crisis, we must concentrate on the application of the science we have, even if it means squeezing basic research. Look at the example of the solid state field, a leading field in the race to apply science. We must remember the solid state is based on basic research of a half century ago. If this generation does not support basic science well, we will be robbing the next generation of it's birthright.

Progress in basic research depends heavily on well supported and equipped individual investigators and small groups of professors and students. Additionally, there are some fields, like astronomy, oceanography, planetary geology, glaciology, and high energy physics, where the individual investigators depend on large and expensive facilities and/or logistic support systems. I believe that, if a field of basic research shows great promise of further progress, it deserves support no matter what it's current state of support is, large or small.

4. Applied Research

There are some fields of research where it is crystal clear that further research, both basic and applied, will reasonably quickly yield important economic returns in new product or process applications. It is in precisely these areas where our international competitors, particularly Japan, excel. In such areas the issue for the federal government is not so much funding as it is finding and facilitating the best institutional arrangements to ensure rapid transition from the research stage to application. Often the answer is simply helping industry alone to do the job, ahd there are ways to help industry fulfill this role. There are cases, however, where institutional innovations are needed. One such innovation is the academic-industrial cooperatives, usually with government funding and encouragement. Another is the agglomeration of people, facilities and funding from several companies to pursue a particular line of applied research. Though much experimentation in such arrangements is needed, there are already some signs of success.

5. The Environment

Of particular interest to all of us is what can and should be done to preserve and enhance the environment on a global, national, regional, local, and personal scale. In some environmental pollution areas, there is excellent understanding of the problem and the ameliorating actions are quite clear. Often the economic effects of the action are large, and there is argument as to who is to blame and who should pay. There are some areas of long range and great significance where the causes and consequences are not fully understood, yet the economic effects of the ameliorating actions are huge. In these areas such as global warming, acid rain, ozone destruction by industrial gases, leaching of long-term radioactive waste, agriculture and industrial chemicals into the underground water supplies, etc., the full capabilities of the scientists and engineers must be called upon. Many of these problems, such as global warming, and acid rain bring together the fields of energy, environment and economy, and the government responsibilities in research, legislation, regulation, and enforcement. I can think of no more appropriate problem area for the Science and Technology Advisor to exert leadership, calling upon the governmental, academic, and industrial talents to the fullest.

6. Science Education

Strengthening science and engineering education is a high priority problem for the country, one in which many from the science and engineering communities should participate. Our university education system, especially at the graduate school level, generally receives very high marks here and abroad. The problem of getting a higher percentage of native born Americans to take graduate degrees, especially the doctorate, is partially solved by the high interest, capability, and participation of some of the new and potentially new Americans who are coming to this country either as immigrants or as students. We have had a long term tradition of getting our science and engineering students and teachers from abroad, and I think we should continue the tradition for all it is worth.

There are serious problems in K-through-12 education, mostly due to a lack of qualified teachers. The system is spotty, with some schools doing a fine job and others a very poor job both of teaching and motivating students to a life in science or engineering. There are some interesting and apparently effective new programs with evidence of success: one such is the selection of, or building of, a school concentrating on science; another is the New Jersey program to waive teacher training certificates for retired scientists and engineers, thus increasing the supply of teachers and getting those who are well trained in the subject matter. Other helpful programs are those summer and weekend courses given at government research laboratories. For example, those at the the Department of Energy's laboratories have achieved marked successes, and the Department is incouraging, nay requiring, its laboratories to do more. Continuing attention and innovation is needed. Since K-12 education is the responsibility of local school jurisdictions, the Federal Government must adopt a role of encouragment and facilitation, another place where the Science and Technology Advisor's power is needed.

7. Conclusion

Finally, we are rich in talent and facilities, and ideas abound for strengthening our science, engineering, and technology in this country. So many science fields show great promise. We should not let our opportunities go to waste; indeed it is our responsibility to seize them. Strong implementation of the Science and Technology Policy Act of 1976 will carry us far toward our goals.

Senator **Gore** [presiding]. Thank you very much, Dr. Stever.

I have had an opportunity to read every word of your testimony and appreciate you coming here to present it.

Let me recognize Senator Bryan for the first round of questions.

Senator **Bryan**. Thank you very much, Mr. Chairman.

Dr. Stever, let me begin with you, if I may. I thought I detected a subtle distinction between the testimony that you offered and Mr. Bloch offered on the point of allocating our resources.

You stressed, I thought, a bit more than he did, the necessary aspect of supporting rather large expenditures as part of a support system, and you cited the global change research that was done in the Antarctic, for example.

My question to you would be, having heard Mr. Bloch's discussion of what he thought we should do, in terms of allocating priorities, and just to paraphrase again very briefly, he said that the most important investment was human capital and emphasized the need for equipment and support for the government labs in this country and other types of efforts of that nature.

He placed in the second tier what I would call the big ticket items, the items that we hear about in this committee a lot, and you all are so very familiar with, the Space Station and the Super conducting supercollider and all of that rather exotic type of technology. And I do not mean that to minimize it in any way.

What guidance would you give this committee, in terms of recognizing the finite limitation of our resources? How would you advise us to spend our money, such as we have it, in the area of science?

Dr. **Stever**. I am very glad you asked that question. Every time we hear about these new programs, which are very exciting, we start comparing that against other fields of basic research, more teaching in the universities and so on, that we say are fundamental and cannot be forfeited. And I agree with that.

Our real problem is that we are comparing things at the cutting edge of these different fields with a lot of stuff down in the system which could easily be wiped out.

We ought to develop an anti-priority list that we would begin eliminating to get some of the money to fund some of the things that are out on the very forefront.

And when you look at the big projects, I think you have to ask yourself, is this field of science really at the point where they need it to continue making progress? I feel that if a field of science is showing great promise, then we better be very careful if we cut them off too soon.

So I would look to other ways to get some of that support.

You know, we made studies about that, but no one seems to be willing to cut something off that is not as important as it used to be but which is still using money.

Senator **Bryan**. Dr. Stever, everybody here is on the edge of their chair, including this senator, eager to hear you list the anti-priorities.

This is a chance for you to hit a home run.

And we appreciate the candor with which you have all expressed yourselves so far, so please go on.

Dr. **Stever**. Well, I will confess, I am a retired science adviser.

Senator **Bryan**. You may be the most candid of all, then. Please, what do you think we are doing that we ought not to be doing? Because there is no question that the Congress understands the nature of the problem. What are those projects, and I think you are talking again about, in my term, the big ticket items, that are not to a stage where they show great promise.

The difficulty is that we have very erudite people who come in here and tell us that each one of these things is at the threshold of a new advancement of civilization. It is very difficult for those of us that are laypeople, who do not have a highly technical background, as you do, to know which of these projects does, in fact, represent the cutting edge.

Dr. **Stever**. Well, I think, if you are careful, you can get help from the total field that is involved.

Let me give you a story. When I was head of NSF, the astronomers came in and said they had made a study under the auspices of the National Academy of Sciences. And they said here is our list of important astronomical facilities. And they gave me a list of 10.

We just defended the first one, on that list, and we were gung-ho for that. And they said, but what about the other nine?

Well, slowly but surely, they worked on that list.

And I think the peers in a field of science can help you prioritize. And I believe that this process does go on in fields other than astronomy.

That is a tough thing. But I would not want astronomy cut off because at that point you may find some astronomical things down below that are not so good. I would not want high energy physics cut off, if all of the physicists feel SSC is the important thing. I would not want the South Pole cut off if the people in environment think that is a very important thing.

I think you have got to look to other things. And this is where the science and technology adviser can help, and other people in the field can help you get those priority lists.

Senator **Bryan**. Dr. Stever, it has been my experience, brief as it has been in the Congress, that seldom on any subject is there a unanimity of opinion; it is as elusive as the search for the Holy Grail.

I mean there will be those that will argue that a project is essential and that Western civilization's future depends upon funding the project, while others would assign it a lower priority.

Dr. Press, let me give you and Dr. Keyworth an opportunity to respond to the general thrust of my question.

Dr. **Press**. I would hope that when the President's budget for science is presented to the Congress, it is explained in a better way than it has been in the past.

Certainly when I was science adviser, we could have done better.

They should list their priorities, and they should tell you how they arrived at them and why they want to do these things, and then the debate can begin in a more rational, focused manner.

It is true you do have people coming in here and telling you to do all sorts of things, and it is hard to discriminate between them. But if the process started in the way that I just outlined, I think it could organize the discussion in a better way.

With respect to the basic thrust of your question, we cannot do everything, so how do we decide?

I will answer it in a somewhat different way than Dr. Stever did.

You know, to double the entire basic science budget of the United States in five years would require a modest increase of $1.5 to $2 billion a year over the next five years. I know you hear this very often, but it is not a lot of money.

The historic record of rates of return on that sort of investment and the potential for the future in terms of everything we have been talking about to me justifies that attitude rather than saying what can we cut.

Do you know 25 or 30 years ago molecular biology was being debated as an area, an uncertain area, perhaps a dead field, not much potential. It now has spawned an industry whose potential is enormous, as much, perhaps, as the electronics industry HT superconductivity.

The latter field was opened up by IBM in Zurich, but this nation's scientists showed an ability to respond very rapidly and take it over and even push the progress more rapidly and raise the temperatures; and all of that was due to about a half dozen small National Science Foundation grants in material sciences.

This was not at the great universities, incidentally, but at some of the state universities with high aspirations for getting ahead. That lone British scientist in Antarctica with his device for measuring ozone look at the great discovery that he has made with potential traumatic consequences if we do not do anything about it. That is a consequence of the support of small science, not with any particular outcome in mind.

Today pure mathematics is contributing as much to potentially commercial products as some other fields, and that continually amazes me contributing to the evolution of a whole new series of encryption devices that will be important in the commercial as well as the defense sector.

There are so many examples of serendipitous results from the broad support of science, for example, look at what antibiotics have done for medicine.

And so, I urge that we not have the attitude of what can we cut in order to do other things, but that we take a broad view of the importance of all of science and its relatively low cost compared to the returns.

I hope that we are not in a budget deficit position forever, and in the years ahead when we get out of it, we can think more broadly in this way.

Senator Bryan. Thank you.

Dr. Keyworth.

Dr. Keyworth. Let me make just a few comments that probably are guaranteed to make no friends, but first——

Senator Bryan. This could prove very interesting.

Dr. Keyworth. The big versus little science debate is a total non sequitur. That is a debate between—in my opinion—between funding recipients, not a debate that really represents the kinds of policy issues that are out on the table.

A second point is that policy in government depends upon a cohesive focus in the government.

Erich Bloch referred earlier to the lack of a cohesion in the government. I thoroughly agree with him, and I will only throw out and say that I see no way by which we can have a cohesive focus in technology and R&D investments in science and technology policy in this country unless we have some cohesive focus.

We do not have in this country any department of science and technology, and yet we have a Department of Labor and a Department of Transportation, et cetera.

And, finally, I will offer you two examples of places where I believe we could reduce funding significantly, and I think the data has been out on the table for several years.

One of them is the Federal laboratories. David Packard did a study for us when I was science advisor to President Reagan in which it was quite clear—and I think not even terribly disputed—that the amount of investment we place in the Federal laboratories is by no means commensurate with the amount of result that we return.

Another one in which I believe there is a reasonable consensus within the scientific and technical community, at least, and that is that the space station is incapable of preserving U.S. leadership and focus for a growing, healthy, leading space program, and so I offer you two areas where I think there is at least a lot of information for some cohesive decisionmaking.

And, finally, I would just conclude by saying that I was attempting in my prepared testimony to point out one area that I at least—and I think many other people in our society believe is crucial to our future economy and an area where we need to apply a lot of attention—in other words, a very high priority that I believe will emerge and I think it will test our ability to set these priorities.

Senator BRYAN. Let me shift the focus for a moment. We have talked a lot about the role of the Federal Government in allocating resources and our documented failures.

Let us talk for a moment about the university systems itself around the country. What kind of a job are they doing in terms of establishing the kind of priorities in basic and applied research that you think ought to be done in order to keep America in a world class leadership position in these evolving technologies? Or do they need to reexamine the way they are spending their resources and the way they are structured in terms of handling our scientific issues?

Dr. Keyworth, why do we not start with you and then work back down if you have a comment.

Dr. KEYWORTH. First of all, I think the universities do a very good job, but let me just qualify it first. The universities have—their direction is heavily influenced by where graduate students choose to apply their research efforts.

There is a tremendous amount of flexibility, willingness to move, and you can see fields emerge as the excitement in that field, exciting opportunities develop from year to year.

I think the reason why there has been so much emphasis in the last six or seven years to develop these engineering research centers and new forms of industry, university relationship is, however, to bring that same kind of flexibility, if you wish, into technology.

It is very strange that we did not have, for example, very many universities in the United States that pursued polymer research at a time when the demand for polymer research scientists and engineers was really quite large.

And so, I think the only place where problems have occurred that I worry about in university priority settings is where the universities have been so isolated from the market itself.

But, in general, I think, we are pointing out one of the strongest segments of our research and development enterprise in the United States. In fact, the strongest enterprise, our universities.

Senator BRYAN. Dr. Press.

Dr. PRESS. I agree with the very last part of Dr. Keyworth's remarks. The research university system in the United States, the 100 or so universities that combine teaching and research, that is a remarkable system. It is the envy of the world. The Russians are now trying to emulate them, changing the nature of their universities, and the Japanese are trying to do that.

The universities have delivered on their promise. Their support by the Federal Government and the state and local governments and philanthropy has really paid off in terms of discoveries, making American science preeminent.

However, it is not a static situation. The ability of the universities to respond to the challenges of the very next decade, to my mind, is uncertain.

The Federal Government is an uncertain provider. Lots of shocks in between periods of support. There are demographic changes, as my generation moves out of the universities and a new generation moves in. Where will these people come from, the new young faculty?

There is going to be a shortage. Other careers seem to be more attractive and so how will the universities renew themselves?

Perhaps even more important, the very progress of science is redefining scientific fields, basic versus applied, removing the boundaries, creating new ways of doing science, requiring centers rather than disciplinary departments and so on. How will the universities respond to those challenges wrought by scientific progress itself?

So, they are great institutions, but we should worry about their future.

Senator BRYAN. Dr. Stever.

Dr. STEVER. I like what has been said. I will stand on that.

Senator BRYAN. One last question, then I will yield my time to the chairman.

Let's consider SDI. Whether you agree or disagree with it, let us put that aside for the moment. Clearly, the previous administration was successful in enlisting the broad base of support for it, at least in part due to what I would call a sprinkling effect; that is, money was placed out there on the table. Many, many universities across the country were offered a piece of that pie, thereby generating the domestic political support in congressional districts around the states for SDI.

Not being a member of this institution, it struck me at the time that in effect an advocacy group was established that may not have been premised solely upon merit or priority, but on the availability of money and, therefore, our priorities in terms of allocating those resources for science in a generic sense may have been skewed.

Dr. Stever, any response to that?

Dr. STEVER. Well, I think that Dr. Keyworth should answer the central thrust of that, but let me say that those advocacy groups are very worthwhile.

I think one of the best things that the National Science Foundation has done in its past is to run the teacher-student summer institutes. That could be done on a broad geographical basis, and NSF got a great deal of credit for supporting work at smaller universities and so on.

Also, the work was very good. I believe that more people have come up to me in my later life and said that the thing that influenced them most was an NSF summer institute. That was an example of advocacy and a very fine thing, I believe.

On SDI, I think there is more than one edge to your question, but let me address one of them. I think that a lot of the research that was done in the SDI program is something that we will be glad we have done. Whether in building that constituency you also had to do things that were not of long-lasting value I cannot judge at this time. Perhaps Dr. Keyworth, who was closest to it, could.

Dr. KEYWORTH. First, I think little more than $100 million out of a $3-$4 billion budget, depending upon which year, was actually allocated to universities. It was an effort not to develop a constituent. It was an astute effort on General Abrams' part, in my opinion, to go out and add the kind of talent that we have allowed to get further and further away from the defense establishment.

I would make another observation. I think we have seen it as recently as last week. The constituency that supported SDI in this country was not in American universities. In fact, the most important constituency was in the Soviet Union. I mean, from the beginning Andropov's response to SDI all the way up to Shevardnadze's response with Jim Baker last week is what has kept SDI highlighted in the minds of the American public and not the universities who received $100 million, approximately one-fortieth of the whole SDI budget.

So, I think it is a public—a poor example of pork and science.

Senator BRYAN. Dr. Press, your response?

Dr. PRESS. Well, it is a complicated issue, and we are running out of time. But I agree with Vice President Quayle.

Senator GORE. We have time.

Dr. PRESS. I agree with Vice President Quayle when he said that SDI was oversold in terms of what it might accomplish, and if that is the case, then it may have been overfunded in those years.

It is a very expensive way to support good science, namely, the spillover from developing highly specialized defense technology. If that is an important rationale for the SDI, I think it is not the right one.

It is the case that in the sixties we used to get a good fraction of a dollar back in terms of transfer to the civil economy from defense-supported work integrated circuits that built our computer industry, for example.

But I think most observers these days view the civilian return on the extremely specialized systems that are required by modern defense as much less. In fact, the government may be getting more from the civil sector to meet its defense needs than ever before. And so the basic answer to your question is there may have been that kind of bias and distortion, but I am not sure what the long-range impact in terms of civil competition or economic success will be.

Senator BRYAN. Thank you very much.

The CHAIRMAN. Thank you. I would yield my time.

Senator GORE. Thank you very much.

I have a number of questions about the role of OSTP and many of the other generic issues that we are trying to cover here. But since Senator Bryan opened up the question of SDI, let me just ask a couple of brief follow-up questions on it.

I agree with you, Dr. Keyworth, that SDI has certainly been useful at the negotiating table. I have not been a supporter of the SDI program, the way in which it was designed by the last administration.

But, even opponents of the program, I think, ought to acknowledge that at least a part of the response by the Soviet Union in Geneva has been due to their concern over what might come out of the program.

That, it seems to me, the best argument you can make for what was done in this program. But, the public was given the impression by the statements from President Reagan and from his advisors, Secretary Weinberger and others all the way down, and including his science advisors, including yourself, that the President's view of a comprehensive umbrella was scientifically realistic.

Dr. Press referred to Vice President Quayle's latest assessment of that assertion as political jargon. You know, if we want to pull off a sting on the Soviet Union and make them believe something that is not true and get negotiating concessions by using that strategy, then I am prepared to believe that is worth considering. But, did you ever really believe that was scientifically feasible?

Dr. KEYWORTH. I most certainly did, and, Mr. Chairman, we are well aware of the power of time and the media and debate to exploit political rhetoric.

But the fact is, that the President said in that speech, that what he wished to do was to put us on a new path in the way we thought about nuclear weapons. The President never said that SDI was going to give us an impenetrable shield; that was political rhetoric that developed afterwards. The President never called for that.

What the President did, was try to deny the means for what we, today, refer to as counter-force attack.

The instability that has occurred, as missiles have gotten more prolific, more accurate, and MIRVed; SDI was designed to move us, in a way, backwards in time through technology on to a more stable environment.

The President said, and the President said it again, and the President understood the issue intimately. I think that I probably am well-qualified to make these comments since he and I worked together on the original SDI speech, and very little of our input was put in it. The President understood it perfectly.

I think Vice President Quayle has been taken out of context, from his own terminology, in going back and looking at that.

I think we should not confuse a long-range public goal to see ourselves, established by President Reagan, to see ourselves on a far more stable nuclear balance and relationship with the Soviet Union, than this ridiculous Star Wars concept that Senator Kennedy created, or this impenetrable shield that has been allowed to develop over the last six years.

Senator GORE. Again, this is not one of our major topics to focus on today. Senator Bryan opened it up, and I do not want to belabor the point for very long.

I do want to follow up on that, though, because what you just said left the impression in my mind, that from the very beginning, you and the President saw this as a way to prevent a counter-force strike by the Soviet Union, and as a way to complicate a Soviet strike against our ICBM silos.

And the impression that it had a broader mission than that was created by political opponents of the program.

That is really not the way I remember the debate. I mean, we could go back and get the exact statements, and if we were having a hearing on that subject, we would have them here. But, gee, the President certainly left the impression on many occasions that this project was not just to defend our weapons; it was to defend our people. It was to prevent an attack that could hit cities, as well as missile silos, and make the whole idea of a Soviet ICBM attack obsolete and impotent.

Was that not the phrase that was used?

Dr. KEYWORTH. Absolutely. In fact, the President would tell you today, and we discussed in the week before that speech, the implications that clearly implied we cannot protect ourselves against a counter-force attack. We, also, cannot introduce a new stability in the nuclear balance unless our strategy is to protect people.

That protecting weapons, alone, is, in fact, in my opinion, an unviable way of denying a counter-force attack.

Senator GORE. So its mission was not just to protect against the counter-force strike?

Dr. KEYWORTH. Let me try to make the point clearer. I think if you get into this in detail, you will find that you cannot protect this country, or any country, against a counter-force attack, unless you are able to do what we call, "protecting" the public, which means, intercepting a ballistic missile in the very early stages of its flight, before you even know where it is going to be attacked.

It is not a nuance, but it is truly a question of the correlation between protecting people, and being able to deny any incentive for a counter-force attack.

The idea that protecting the weapons, themselves, is the way to deny a counter-force attack, I think is nonsense.

I think the original concept of deception, of mobile basing or of deceptive basing, is a far better way to protect the weapon system itself for a temporary period; but it changes the nature of the equation. It is not protecting the people.

Senator GORE. I certainly agree with that, and I have felt for nine years now, that single warhead-mobile missiles is a far more sensible way to achieve that objective.

And, again, we are not here to talk about this.

You and I could debate this for a long time, and it would be fun, but I think the point that ought to come out of this is that the President's science advisor has a set of responsibilities to the country as a whole, as well as to the President as an individual. And where these scientific questions are involved, it is awfully important for the advice given to the President, and the statements made to the public, to reflect, you know, the best scientific judgments that we can come up with.

I have not really gone back to research your statements about the capabilities of that plan and how realistic it was to expect that it could be a comprehensive, or nearly comprehensive, defense.

But I remember making a lot of speeches immediately after the President's proposal, saying: It is pretty obvious what is going on, there is a bait and switch routine here. We are going to promise the moon, and then we are going to switch it back to a counterforce defense of a kind the country turned away from in 1972.

And, sure enough, that is exactly what happened. One of the difficulties that I and others had in getting that point across was, that there were continuing assertions from the White House that the more expansive capability was scientifically realistic.

But, again, I do not want to belabor the point.

Let me ask about the Science Advisor and the Office of Science and Technology.

The primary duty of the science advisor is, in fact, to be a personal advisor to the President of the United States on science and technology policy. Do all three of you agree with that?

Dr. PRESS. Yes.

Dr. STEVER. Yes.

Dr. KEYWORTH. Yes.

Senator GORE. Now all three of you have been science advisors. How realistic is it to expect that a President's science advisor would have time left over, after that primary responsibility is taken care of, to spend energy and time coordinating policy among the various agencies for science and technology are concerned?

Can OSTP really provide inter-agency coordination and play that large a role in being the focal point for science and technology policy, not just for the President, personally, but for the Administration as a whole?

Dr. Press?

Dr. PRESS. I think it can. It needs adequate resources, in terms of staff. I am glad to see that President Bush will increase the staff of OSTP to something like 30 or 40 people. It needs a larger budget.

Senator GORE. This subcommittee put the money in for that, and we agree with you.

Dr. PRESS. Congratulations. You did a fine thing.

Senator GORE. Thank you.

Dr. PRESS. I think the mechanisms are in place. The Federal Coordinating Committee has been an under-used entity. I am glad to see that there is now a role model of a very powerful inter-agency committee on earth sciences that is, for the first time, beginning to coordinate a response to the global environmental issues.

It shows what can be accomplished. This particular committee has the support of OMB; their proposals are being accepted. It seems to work.

So I think with adequate staff, and access of the science advisor to the President, to the budget process, and to all of the important councils, including the National Security Council, that office can function as Congress had in mind during Guy Stever's administration when it created the OSTP.

Senator GORE. Dr. Stever.

Dr. STEVER. I agree with what Dr. Press has said and would like to emphasize one thing. It is very important for the science adviser to have those close connections with the other units of the White House when he performs that coordinating role.

I discovered, and I suspect others did, too, that when we tried a coordinating activity through FCST (now FCCSET), the agencies responded very well if two conditions were met: there was money involved, and there was clearly an interest of the President.

So the coordinating role of the science adviser has to be backed up by close association with the OMB and other units of the White House.

But with that, he can do it.

Senator GORE. Dr. Keyworth.

Dr. KEYWORTH. I have a few reservations, and it has nothing to do with time; it has to do with control of money.

We know, in other institutions, corporate, particular that, pure staff functions, we have no direct control over funds; very rarely have control over directions and policy.

The difficulty of the science advisor and staff, and in accessing the President, I think, is a bit of a decoy.

During my five years, we had over 40 people in the office. We were not staffed short. We had more than enough access; we had routine access to the National Security Planning Group discussions—that was not the problem.

The problem was maintaining financial control; that is very much a personal relationship with OMB, as well as a personal relationship with the President.

But, over time, to establish a clear technology policy such as this hearing has been discussing today, I think it is beyond the purview, over any extended period of time, of a science and technology adviser, unless, somehow, more direct control other than strictly coordinating, comes over the funding for R&D.

Senator GORE. So you have proposed in the past, and still favor a cabinet-level department of science and technology?

Dr. KEYWORTH. Of some sort. Yes.

Senator GORE. And neither of our other witnesses on this panel really favors that approach?

Dr. STEVER. I would say I would, but the "of some sort" is the worrisome thing.

Every time you try to put together one that is meaningful, it turns out not to be very meaningful, just a few odds and ends collected.

But if a science and technology really did have broad coverage, it would be fine.

Senator GORE. Dr. Press is not anxious for me to press him on the subject.

Dr. PRESS. No. You know, you get conflicting advice from the science community, but I think in this case, the overwhelming advice would be not to do it. And if that is their instinct, I think you should—in one of the few occasions when they agree with each other, you should take that seriously.

Senator GORE. Okay. I do.

Now, where the role of the President's science advisor is concerned, we have talked about his primary duty to assist the President in assessing these problems and issues and opportunities. We have talked about that person's role in coordinating the various agencies with a role in science and technology.

What about the role of the OSTP in dealing with the technology concerns of business leaders, as they relate to the policy process in the executive branch?

If I am a business person concerned about declining technological capabilities in my industry, and I have come up with some ideas that I think that could turn the problem around, how do I convey that message to the executive branch?

Does OSTP make an effort to collect such opinions, to harvest such ideas, process them, and make them understandable for the President and the executive branch agencies? Should it?

Dr. Keyworth.

Dr. KEYWORTH. It was OSTP that was instrumental in setting up the first President's Commission on Industrial Competitiveness, and I think was certainly a key.

Senator GORE. Was that the——

Dr. KEYWORTH. John Young.

Senator GORE. Yes. But then you would not give him a room for the press conference to release the report?

We had the vice president of his new group, the council on competitiveness, up yesterday. After the report was done, the administration did not want anything to do with it.

I got him the room for the press conference. I remember it very well. They could not even get a room to announce the release of the thing.

Excuse me. Excuse that outburst, but, you know, that is not the best example.

Dr. KEYWORTH. Mr. Chairman, if I were to call that a crass oversimplification of those circumstances, I think I could not be accused of overstating it.

Senator GORE. All right. Well, go ahead.

Dr. KEYWORTH. I was there. There was a debate amongst the members of the committee, as well as the administration over, at which point, we were going to call it concluded.

That was a logistical error, and it was almost insignificant.

We had press briefings all over the United States, including in Washington.

Senator GORE. Did Mr. Young ever publicly present the report to the President? Did he ever hand a copy to the President?

Dr. KEYWORTH. I am not hedging. The best of my memory is that he did, but not in any public ceremony.

But, look, the Education Commission's report, that had a tremendous impact and support by the administration, Gardner never submitted that to Ronald Reagan.

You asked me a question, or us all a question.

Senator GORE. And I interrupted your response. Go ahead.

Dr. **Keyworth**. The fact is, that OSTP did that.

There are several organizations in the government that do the same thing.

I think it very interesting to note, and I will mention it, almost as a non sequitur here, that DARPA, today, is probably the single, most influential focal point for industrial leaders, outside defense, with ideas to access the Federal Government and the executive branch, and I find that, simply, interesting.

Senator **Gore**. Yes. In fact, that was the real focal point for all of this HDTV activity, and it came to the same result as the Young Commission report—nowhere.

Dr. **Keyworth**. Except, having served on the Young Commission, myself, I think I can say humbly, I do not think that we were terribly sophisticated in our recommendations, and it was a fairly early stage in the public debate on competitiveness.

Senator **Gore**. I thought it was an outstanding report. I thought that it was an excellent report. I think their follow-up documents have been outstanding, and I think the recommendations from the Young Commission were rejected out of hand, and given as low a profile as they could possibly be given, to the point where President Reagan's science advisor does not know whether Mr. Young ever actually gave the report to the President or not.

I think that they were rejected out of hand because they pointed toward a role for government that was inconsistent with the ideological model, which former President Reagan insisted be followed. And there are certain strengths to that model. As our witnesses, yesterday, pointed out, there are certain advantages which come from that approach. But there are also certain weaknesses, which the Young Commission, in my view, documented quite thoroughly. And I think we would be better off if we had taken their advice.

Let me refer to your own candid statement here this morning, Dr. Keyworth.

> My own experience in OSTP coincided with what I see in retrospect, was the beginning of the rapid change and pressure caused by deteriorating United States position in world markets; we could have been more aggressive ourselves in venturing into technology policy. But the signals were still pretty mixed about our national position, and about the ways to respond. I think those signals are far clearer now, and we ought to be better able to respond.

I welcome the candor embodied in that statement very much, but I think that the Young Commission presented those signals pretty clearly.

And, again, in retrospect, if we had looked at those, at the way they were presented at that time, I do not think we would have to be saying, "in retrospect." Because I think they raised the alarm, sounded the alarms pretty loudly.

Dr. **Keyworth**. May I make a comment?

Senator **Gore**. Sure.

Dr. **Keyworth**. Well, my comments were talking about signals from the Nation, not talking about from the President for whom I worked, by the way.

What I wish to clarify here is the difference between your implication that there was some kind of a stifling of the Young Commission by ideological differences, which was most certainly not the case.

The Young Commission identified the national problem of competitiveness well, in a way that we agreed. What it did not do was provide very many manageable, practical solutions. Things such as moving to a more incentive- and investment-based tax system are not politically easy.

What it did propose, however, and I think it is an excellent example, is it proposed the very Department of Science and Technology that I have been talking about. That was discussed in a Cabinet meeting devoted to that service. It was discussed with John Young and several members of the Cabinet.

It was probably the most drastic and, let us say radical proposal the whole Commission made, and it received a lot of attention. Ed Meese was a real supporter of it, for example, when he was counselor at that time.

What I wish to take exception to is the idea, even if it persists in the Council on Competitiveness today, that that was not taken seriously. It was taken seriously. Most of the issues simply were not implementable, had been implemented, or really were not adequate solutions.

Senator GORE. Well, I think the truth of what actually did happen will be found in the dialogue that we are having and in statements made by others who are not here. I will just tell you where my information is coming from.

I talked with John Young himself and with several members of his Commission at the time the report was prepared for presentation, and I do not think it is at all inaccurate to say that they were bitterly disappointed at not being able to get any attention from the President or the Administration in any formal way, or in any way that called the attention of the Nation to the urgent recommendations that they had for the country, and I think that is the way they still feel today.

Now, I am not saying it was stifled actively so much as ignored, and I do believe that the reason the recommendations were ignored have to do with the overall approach in the last Administration to the proper relationship between government and society, between government and industry, between government and our national goals.

I think that it is abundantly obvious that the overall ideological thrust of the last Administration was to say to the country, look, government has been playing too big a role. Let us scale it back and get it out of so many things, and the American people have supported that thrust in many of its iterations.

This is one area where I think it was too broad a brush and used inappropriately. Now, that is just my impression. I do not say this in an accusatory way. It is just my impression of what actually happened.

I really think that we ought to go back to some of the approaches recommended by the Young Commission where science and technology policy are concerned, where the coordination of the government-industry-university relationship is concerned. But I mean, that is just my view.

Dr. Stever, you have had your hand up.

Dr. STEVER. Well, I would like to say that this is an immense problem we are trying to push around and it has a much longer history.

About 20 years ago, there was much more reluctance on the part of people in industry to think about things that the government could do. At the National Science Foundation there was a RANN program that I think, gave the first grant to the Industrial Research Institute to study the government relationships and it has been growing ever since.

The productivity studies were begun, and slowly but surely the relationship between government science and technology and industry has grown stronger. A lot of the ideas are sufficiently good that they are going to stay around awhile, in my view.

In Dr. Press' time, President Carter's time, they did a study that came up with a number of very good suggestions. Again, some of them could not be implemented at the time, but it was one step along the way. If these ideas are good, they are going to come back again and again, because we are building closer relationships.

At the academies there are many more studies that involve the industry-academic-government interlocking, and many, many more meetings today in which leaders of industry sit down and so I think we should be pleased with some of the progress we have made and keep hammering away at the problem.

Senator GORE. Let me take a specific example and ask you to respond. The generic question which got us into this discussion here was whether or not OSTP is the right place for somebody in industry with a specific concern about science and technology policy to go, and I guess what you are saying is yes.

But let me give you a specific example and ask you to elaborate. I Chaired a session this week with Dr. Paul Berg and Dr. Jim Watson on the future of biotechnology and some of the business people who are looking at the U.S. position in biotechnology have highlighted a major concern which Drs. Berg and Watson amplified.

They are concerned about our patent policy, the mechanics of our patent system and the near breakdown in our patent system. The difficulty of getting people to review the new patents who really are up on the latest advances has made the system far less useful for the protection of innovations by American inventors.

Now, let us say I am a businessman in biotechnology and I have all the arguments marshalled, I have all the facts, I have a very clear case to make, and I have a set of recommendations that need to go to the President of the United States, need to go to the Congress, and need to be embodied in changes in the Patent Office as part of science and technology policy. Should I go to OSTP? Is that the place I ought to go?

Dr. STEVER. Well, that plus the Commerce Department.

Dr. PRESS. Let me give you a general answer and then get back to the specific question. We will start with the principle. I think nobody will disagree with the statement that there is no higher priority for the United States than its future economic success, jobs, economic growth, all of that.

Without economic growth we will not have the basis for national security in a military sense, if that is what we need in the years ahead. We will certainly not be able to create the wealth to tackle some of the severe problems we face as a Nation—poverty, education, health needs, the homeless.

At the present time, the President sees his national security adviser every single day. There is no higher priority on his calendar than a meeting of the National Security Council.

I believe that these issues of economic growth and competitiveness and our future are just as important. There is no mechanism in place at the present time for the President to attack these issues with the priority of the NSC and the security adviser.

Nothing is in place at the present time to prepare for our future, to organize our cross-government policies. I think that we need a mechanism, perhaps by legislation or Executive Order, to address these things.

OSTP has to be part of this mechanism, along with the Secretary of the Treasury, and the State Department. It involves trade policy, it involves all of the issues that you know so much about.

Under those circumstances, if this mechanism, this entity, recognizes a problem in patent policy, for example, as you have just indicated, there would be a way of dealing with it not just in isolation but in relation to other policies.

So your question should be not what OSTP should be doing, but what should the White House be doing by way of preparing for our future with a new approach to the issue of competitiveness, giving it the priority of the National Security Council.

Senator GORE. Well, that is my question and your response is that OSTP, as it is presently organized without this framework and priority for the President's attention, is not capable of playing that role unless it is changed and reorganized?

Dr. PRESS. No. What I am saying is that the solution will lie in an integration of technological and economic policy. OSTP is not going to be the Government of the United States involving everything. It can do the technological policy, but not the rest—the regulatory policy, the trade negotiations, and so forth.

Senator GORE. But the science advisor is seen by some as the person through whom the President of the United States plays that coordinating role, and if an important industry like biotechnology wants to communicate to the Executive Branch about an urgent set of concerns that can be solved, then some people would have the impression that the place to go would be the President's science advisor.

You three have been in that place. If I am that business person, wanting the kind of coordinated response which you have well described as necessary, where is my point of contact? Can the science advisor play that role in collecting those ideas?

Now, Dr. Keyworth, you created a Biotechnology Science Coordinating Committee. I have been in a running dispute with the Administration on whether or not it is working well. I do not think it is working well, but I take it that your motivation in creating that Committee was partly to address those concerns and you would say that with that Committee as backup the President's science advisor would be the right person for this hypothetical businessman to visit?

Dr. KEYWORTH. I think we are confusing a couple of things here. In the case of the national security advisor, first of all the reason why, of course, they meet very often, much more than any Cabinet, is because the government is virtually the sole authority in formulating U.S. foreign policy, the government in its three manifestations, and that is a day-to-day responsibility that no one else will carry out.

The issue that we are talking about here is—and you must recognize it as being a different one—it is a far more strategic issue. I am not saying it is less important, it just does not have its day-to-day manifestations with the government being the only player.

But the national security advisor has the authority to sign letters for the President—for the President. That is a unique instrument of power. The President's science advisor does not have the equivalent power, which is budgetary control.

Now, the coordinating committee that you are referring to in biotechnology is one more manifestation of one of the tools that the science advisor does have, which is strictly coordinating, bringing people together using the power of the presidency and the White House to influence them, but that is what it is.

The reason why I so firmly believe that some form of centralized management of R&D in the government is necessary is because it goes back to that question of control of money, the same, the analog to the way the national security advisor is able to influence foreign policy.

Dr. PRESS. A very specific answer to your question: If I were a representative of industry with a problem, I would always try to get in to see a White House assistant to the President. I would always try to see, at the same time, the cognizant Cabinet secretary.

In the case of patent policy issues, I would try to see the science adviser and perhaps the domestic policy adviser and the Secretary of Commerce.

Senator GORE. Well, the specific example is intended to illuminate a much larger problem, and that is concerns like those of the Young Commission, concerns like those many industrial leaders have been expressing, namely, that our science and technology policy in America is not working well to support their needs and to create a productive relationship between government and business that can improve our competitiveness.

But this is a subject which we are going to continue to explore. There are many other areas that we need to look at, but as you indicated earlier, Dr. Press, time is running on and I appreciate all of the time that you all have given us already.

A couple of brief comments. Dr. Keyworth, I really did welcome your statements on the information superhighway proposal, and with regard to your statements about information streets as well as highways, I agree fully.

I have pushed measures that are a little more controversial than the information superhighway idea to let telephone companies get into the business of distributing cable television as a common carrier, because I think that would be the best and easiest and quickest way to get fiber optic cable to the homes, and so I agree with you on the need for streets as well as highways.

I think that we have to take a different approach to getting there. I think once we have the highways, the demand for the streets is going to help us to find ways to get them there.

Finally, I did not want to let pass your statement about the National Labs. You do not really want to do away with Los Alamos, do you?

Dr. KEYWORTH. No, but all the others.

Senator GORE. Well, I think that response clearly illuminates your point.

And Dr. Press, one other thing you talked about. You list on page eight and nine of your statement, and you presented it orally, a very useful list of factors affecting our failure to use research more effectively in competition. I just wanted to highlight that list.

I appreciate the statements all three of you have made.

Thank you very much.

We have one other witness, Dr. Herbert Simon, the Richard King Mellon University Professor of Computer Science and Psychology at Carnegie-Mellon.

Please come forward, Dr. Simon.

And to all three of these witnesses, thank you very much. We appreciate your time.

Dr. Simon, in addition to the credentials I cited a moment ago, of course, your early work in studying organizations and decision-making earned you the Nobel Prize for economics. And we are honored to have you here as the last witness in these two days of hearings.

In recent years, you have focused on the psychological processes of human decision-making and on artificial intelligence. During the Johnson and Nixon Administrations, Dr. Simon served as a member of the President's Science Advisory Committee. During the 1960s and then again during the 1980s, he also served as a member of the National Academy's Committee on Science, Engineering and Public Policy.

We have asked you here to discuss the government's science relationship and other related matters. And we are grateful for your presence.

Please proceed.

STATEMENT OF HERBERT A. SIMON, RICHARD KING MELLON UNIVERSITY PROFESSOR OF COMPUTER SCIENCE AND PSYCHOLOGY, CARNEGIE-MELLON UNIVERSITY

Dr. SIMON. I am delighted at this opportunity to speak before the committee.

I found the proceedings this morning very interesting and very educational for me. And I would like to do what previous witnesses have done and just simply summarize my written testimony so that we can devote the time to questions here. And perhaps, as part of that summary, to comment a little bit on things that have already been said this morning.

There has been a lot of emphasis in this morning's testimony on the American problem of competitiveness and the problem that all of us think is fairly high on the agenda for our country, and the relation of science to dealing with that problem of national competitiveness.

But, of course, there are many other reasons why the United States has and needs to have a powerful scientific effort and scientific research. And in my testimony I make the observation that government, after all, is one of the major consumers of science, both in carrying out its functions, DOD being a central example of that, but certainly only one among many examples, but also in forming policy, and in the daily programs of the Congress.

We have had mention this morning of environmental matters, and certainly any action that we take in this country on environmental matters has to be informed by a wide range of sciences, some of which really do not exist at the level at which we need them today.

Today there are in place, I think, some fairly useful institutions for providing scientific and technical advice to government. You mentioned my participation in one of them. The Congress and the administration makes very frequent use of the National Academy of Sciences and its associated academies, as a way of connecting with and drawing upon the scientific community in this country. And, in that way, has a rather full and broad access to that whole community.

I have seen those channels develop in the last 20 or 30 years, and I think that they are operating in a generally effective way, although I am sure we can find better ways of making them operate.

Anybody who does any consulting or advising knows that half of the success of the consulting and advising depends not on the advisor, but on the advisee. And so we have to look at the capability of Congress and of the administrative organizations of the Federal Government to receive advice on science and technological matters.

And here I think we have observed Congress gradually increasing its capabilities through congressional staff, through specialized organs, like the Office of Technology Assessment, and the like.

I think that there are some gaps in the system at present that deserve some attention. We have talked a lot this morning about the presidential advisory system in science. I think something was lost with the abolition of PSAC. I understand some of the reasons why that happened. I was on it when it happened. But I think that one thing that is lacking and it is perhaps related——

Senator GORE. That was not the reason, though, was it?

Dr. SIMON. That I was on it? I would like to think not.

But in the discussion this morning, I think we identified the fact that it is not only a matter of presenting advice to the President and to the administration, there is also a matter of responding to ideas in the scientific community and the technological community, having roots of access of those communities to the national government.

And PSAC, to some extent, with respect to the scientific community, but not, I think, with respect to the business and technological community as well, did perform that sort of function.

And I think we probably are clever enough to invent a new kind of structure that would allow more of the funneling in of that advice, so that the President's science adviser and that apparatus in the government is not cut off and isolated from the community outside. I think that is a problem.

I think the same problem exists in some of the other departments of government. I think some of them have—DOD, for example, is fully capable of being advised about scientific and technological matters.

I think one could raise strong questions about whether the State Department is or the Department of Education. We are talking now in this country of the importance of renewing our primary and secondary educational efforts in this country. And the Federal Government is going to have to play some role in that.

I am not sure whether we have the capabilities, in the national departments concerned with this, to do the full job that needs to be done.

Now, one thing that should be obvious, is that many of the scientific problems I have been talking about are social science problems. Almost any broad technological problem or scientific problem we have today, the problem of the environment, involves not merely knowing what the chemistry is of the situation or the physics of the situation, but involves knowing how people behave in response to the kinds of measures that we put into effect.

And there has been some progress, also. We have brought about, in the last 30 years, a full participation of the social and behavioral sciences in the National Academy of Sciences.

We have reasonably good places where the social sciences can go to the funding agencies for support of social science research.

On a quantitative basis, we probably have not given the support to social science research that it needs if it is to participate as a full partner in these problems.

I have in my testimony a good deal of discussion of the American university, and perhaps you will want to ask me some questions about that. Let me skip that at the moment and just say a word or two about university and business relations that we spoke about this morning so much.

There obviously has been a very serious problem of moving the products of basic research, develop the ideas of basic research, developed in the universities, into American industry.

Two comments on that. First, it is my belief that the solution of those problems is going to have to come primarily, not solely, and we have talked about some alternatives, from industry itself.

There are some serious difficulties in the way in which American business has chosen to organize and staff itself, which makes the ~~root~~ from a basic scientific idea to a manufacturable product, and particularly a product that can be manufactured competitively.

There are real problems in the internal organization of American manufacturing concerns, which have, I think, provided the main reason why we have been so often scooped by the Japanese.

Now, some of these may be financial problems, the difficulty of making the initial investment. And we talked this morning about some possible solutions along those lines.

What we did not talk about this morning very much, and which I think is part of the solution, is the government as a customer, who can provide a market for some kinds of new products—I do not mean consumer products in this case—but some kinds of new products, which will encourage industry and make it profitable for industry to do the R&D and the conversion into manufacture that we think is necessary.

I think the remark was made this morning that the defense establishment performed this function for a considerable period of time, and that, for a variety of reasons, especially the esoteric nature of the devices that the Defense Department needs now, that is not being performed as well at the present time.

But I think if we put our minds to that one, we could find another role for the government in that respect.

We could also find a role for research supported by the government. I think we would have known a good deal earlier about the nature of the Japanese problem and the nature of the advantages that the Japanese had over us in several industries if we had a larger group of people in this country who were doing research on questions of organization, another aspect of social science research, who knew something about the Japanese culture, who knew something not only about the Japanese traditional culture, but the Japanese manufacturing culture.

And that band of researchers has been a very thin red line of warriors, who, I think, for that reason, perhaps did not bring that message to the attention of American industry as rapidly and as effectively and forcefully as it needed to be brought.

But let me stop with that and let you decide what aspects of this you would particularly like to hear more about.

[The statement follows:]

Testimony:
Senate Committee on Commerce, Science, and Technology
September 29, 1989

Herbert A. Simon
Carnegie-Mellon University

My name is Herbert A. Simon. For the past forty years, I have been a member of the faculty of Carnegie Mellon University in Pittsburgh, in recent years as Professor of Computer Science and Psychology. Throughout my career, I have been studying how we human beings make decisions and solve problems, and also how we can use computers both to study and to augment our human skills. Since decision making cuts across the usual boundaries of the academic disciplines, I have had occasion to roam rather widely, not only over computer science and psychology, but also business administration, economics, the history and philosophy of science, and even engineering design.

Scientists are also citizens, and are thereby obligated to pay attention to how science can be used to benefit our nation and mankind generally, and what policies need to be followed so that new knowledge will contribute maximally to human welfare and will cause a minimum of harm in its applications.

I have tried to take that obligation seriously, serving for more than four years as a member of the President's Science Advisory Committee (PSAC) in the Johnson and Nixon administrations, as a member of the National Academy's Committee on Science, Engineering, and Public Policy (both in the 1960s and during the present decade), and as chair of several committees appointed by the National Research Council at the request of the Congress or Administration: for example, one to advise the Senate on air quality standards, and another to review the social and behavioral science programs of the National Science Foundation. Through these and other activities, I have had occasion to think a good deal about American science policy.

The questions this hearing is addressing are not new, but they are fundamental enough to need periodic review in a continually changing world. My answers will not, I think, surprise you, but I will try to carry them beyond platitudes.

Government Support for Science

There are two reasons why government should encourage and support science. First, there will be underinvestment in science if it is left wholly to the private and philanthhropic sectors. Second, government is a major consumer of science, making extensive use of it both in forming its policies and in performing its functions. Let me say a word on each of these points.

Why Support Basic Science?

In the very nature of basic science, the discoverer cannot completely appropriate the value of new knowledge -- it inevitably spills over and becomes available to others. The main product of a piece of basic scientific research is a publication, which anyone can read. The patent system does provide some proprietary protection for knowledge, but the more basic the knowledge the less complete the protection. And that is as it should be, for the whole purpose of the patent system is to motivate the inventor -- but with the final goal of creating new knowledge that will ultimately be available to all humankind.

The closer knowledge is to application, the easier it is for the inventors or discoverers to reap its benefits, and the more strongly they are motivated to invest in research and development. With some qualifications I will mention later, we can count on private enterprises to invest at appropriate rates in applied research and development, because it is profitable for them to do so. We cannot count on them to invest sufficiently in basic research, because the benefits will inevitably be shared with others, and they will stop short of the investment that will most benefit society.

Economists have a word for it. They say that activities like basic research produce "externalities" or "external benefits" that do not accrue to those who invest in the research. The United States has had a century and a half of successful experiences in supplying public support for activities that, because of externalities, would attract insufficient investment if left to themselves. Government contributed, quite rightly, to the construction of our canals and railways, to research that enhanced the productivity of our farms, to the development of the technology that produced our airplane, automobile and electronics industries. And especially since the Second World War, our Federal government has followed a consistent policy of funding a substantial level of basic research in the physical, biological, and social sciences.

Careful analysis -- I think, for example, of the work of Ed Mansfield -- can give us some idea of how basic research contributes to the income and welfare of our society. It is clearly impossible to arrive at any exact dollar measure, because the effects of research are thoroughly intermingled with the many other factors -- natural resources, the motivation of our people, education, mechanical ingenuity, our political, economic, and industrial institutions -- that allowed us for nearly a century to lead the world in living standards for our people, and that spread these benefits, especially the benefits of technology, far beyond our borders to all the countries of the world.

Today we have some concerns about how we can retain (or perhaps recover) that leadership, and I shall address those concerns presently. But in seeking to continue our success, we must not forget what brought it about in the first place -- and support for basic research is certainly one of the important components.

Government Is a Consumer of Research

Beyond the "externalities" argument for government support of basic research, there is also the fact that government is a major consumer of research. The Department of Defense, because of its dependence on high technology, is only the most obvious example. Research is particularly important to government, and above all to the Congress, in its implications for public policy. Without scientific knowledge, it is impossible to devise sound policies for protection of the human environment, and all of you are fully aware of how far our present knowledge falls short of what is required. A scientist, or a group of scientists, can suffer from acute embarrassment when asked how to balance the benefits of improved air quality against the costs of making the improvement.

More than once, scientists asked to answer such questions have come back with the advice, "We need more funds for research," or "On the one hand . . . and on the other." (Senator Muskie used to say that he wished he could hire a one-handed scientist.)

These answers simply measure how far even our best science is today from being able to provide adequate guidance to vital policy decisions. Of course it will never be fully adequate, but we can know a great deal more than we know today about weather and greenhouse effects, about the mechanisms of superconductivity, about the genetic bases of disease, about the structure and function of the nervous system -- the list is endless. Meanwhile, the knowledge we already have is indispensable to the policy process.

Everything that I have said applies, word for word, as well to the social as to the physical and behavioral sciences. Economists, like meteorologists, sometimes have their troubles in predicting the future. But sound economic reasoning is essential for clear thinking about housing, monetary policy, farm policy -- again an endless list. To cite a single example, we are never going to think through the muddle of our welfare policies until we take seriously what economists have said, and have found in their research, about mechanisms like the "negative income tax" for motivating clients to move from welfare benefits to private employment.

Social science does not solve social problems (meteorology does not halt hurricanes). But social science research provides basic factual knowledge and concepts that are indispensable for thinking soundly about welfare, about AIDS, about education, about delivery of health care, about drugs -- about every major problem that confronts government. Good social science often sounds (by hindsight) like common sense. After all, it's about people, and we live amidst them all the time. But we also live amidst atoms and molecules. Common sense isn't enough for understanding atoms and molecules. No more is it enough for understanding economic recessions, or crime, or science education, or decision making in business or the military.

The Government-Science Relationship

During the years in which I have been involved in the politics of science and in science advising, the relations between government and science have been generally good and steadily improving. The channels of communication among institutions have been broadened and strengthened, especially through the activities of what we call the "Academy Complex" -- the National Academy of Sciences and its affiliates -- but through many other institutions as well. Congress and the Administration can, and frequently do, seek the advice through such channels of the very best scientists in our country. However adequate or inadequate existing knowledge may be in any instance, it is readily made available to our government.

Anybody who has experience in consulting knows that a consulting relation will be fruitful only if the client and consultant can communicate. It is impossible to provide useful advice to someone who cannot grasp it: the consultant will not understand what the real question is, and the client will be unable use the answer. The experienced consultant insists that the client devote adequate resources to building up expertise for understanding and receiving the advice; and if that condition is not met, the wise consultant leaves.

Congress as Client

Congress has taken steps to meet this condition as advisee. Congressional staff provides part of the answer. Special organizations, like OTA, are another part. Many government departments have policy groups capable of and eager to communicate with the scientific community. Some are still weak in this respect. For example, I think many of us would question whether the State Department and the Department of Education are organized and staffed to work wholly effectively with the social and behavioral science communities.

In providing scientific assistance to government, the flow of information is not necessarily well-channeled and tidy, especially when questions are controversial. But tidiness is one of the minor virtues. Congress and the Administration should not be the captive of "authoritative" single-channel advice on issues that are, at base, controversial and value-laden. Franklin D. Roosevelt was a master at creating untidy organizations in order to preserve his multiple channels of information. Congress, like F.D.R., should develop its capabilities for sorting out multiple streams of advice, weighing it, resolving conflict.

Congressional staffs provide some of these capabilities; Congressional hearings provide some. We can inquire into the qualifications of those who advise us and the special interests that may bias their advice. We can counterpose one piece of evidence against another and ask the experts to reconcile them. Adversarial procedures are not foreign to government (nor foreign to science, where controversy and debate help filter out truth from error). One does not have to be an expert to maintain a pretty good batting average in choosing among experts.

Advice from the National Academies

One important improvement we have made in the past twenty years in the structure of the "National Academy Complex" is to bring the social and behavioral sciences fully into the picture. These fields now are broadly represented within the National Academy of Sciences; and the Commission on the Behavioral and Social Sciences and Education in the National Research Council is able to tap the country's social science expertise for studies done within the Academy Complex. The Commission is able to make certain also that, when advice is sought involving a mixture of scientific, technological, and behavioral considerations, the full range of relevant expertise is brought to bear.

The Academy is also highly sensitive to the need for both breadth and balance in its advisory committees, and for full disclosure of private interests of members; and it has in place an effective set of procedures for maintaining these qualities. It also has a careful process for reviewing committee reports to make sure that they are responsive to the committee charge. Undoubtedly, these organizational procedures require continual attention and improvement, but they seem to me to be in generally good condition at the present time.

Strengthening Presidential Science Advice

If we ask where there now exist major communication gaps between science and government, one obvious answer is in the White House. We do have a Presidential Science Advisor who has been promised, and I assume receives, good access to the President. But we do not have that plurality of views and knowledge that was formerly provided by the President's Science Advisory Committee (PSAC).

I am aware of the causes for the demise of PSAC -- principally the naivité of one or two members who thought they could simultaneously advise the President privately and give public testimony on the same topics, and in opposition to Administration policy, on the Hill. But the causes do not condemn the institution or reduce the need to reinstitute it or something similar. Moreover, while PSAC, by the nature of its historical origins, drew heavily from the physics community, its successor organization, if one is created, needs to be broadly based in the physical, biological, and social sciences (as does the OSTP). The reasons are exactly the same as the reasons why this broad representation was needed in the Academy Complex.

I am reminded of a research group I once visited that was studying new methods of energy production that tended to put large quantities of very hot exhaust gases into the atmosphere. "Won't that create a lot of oxides of nitrogen?" I asked. "Oh yes," was the answer, "but we weren't asked to look into that." The technological fix that ignores broader consequences is simply not responsible scientific advice. Advice, to be responsive, must take into account -- expertly -- the whole range of physical, biological, and social consequences of action.

General Comments

In summary, then, on Government-Science relationships, I judge the patient to be in good health, certainly not requiring radical new prescriptions. My two main recommendations would be the institution of a successor to PSAC and the strengthening of the abilities of a number of Federal agencies to receive advice in the physical, biological, and especially in the social sciences.

There has been a lot of discussion of the need for a "National Science Policy," but I do not really understand how that is different from the continuing discussion of the policies of science that goes on all the time. There is a broad consensus, periodically reexamined and reaffirmed, that the Federal government has a major responsibility for the support of basic science. There is a continual review of what topics in science need more attention.

The scientific community often feels that it could benefit from a little more stability, especially budgetary stability, than it now enjoys, and I am sure that it could. But there is no way to buffer an activity that consumes tens of billions of dollars annually from the constantly changing world in which it exists. The Congress sometimes feels that the scientific community could take more responsibility for allocating funds among competing claimants (e.g., more SSC or more NASA?), but sober reflection usual persuades us that these are not scientific decisions but decisions about society's basic values, to be made finally through democratic processes.

American Universities

Our American universities, especially our graduate schools, are the envy of the world, and all the world sends its students to them to the extent that resources (theirs and ours) permit. We can ask why our universities are so good, how they can be kept that way, and now they can contribute even more fully to our society. All of these questions come within the purposes of these hearings, and I can only touch on a few points that seem to me to need special attention.

The excellence of our universities rests both on certain organizational and institutional features and on the quality of the people they attract as faculty and students. Unlike universities in most other countries, they are both highly diverse and highly competitive along many dimensions. They compete for students and they compete for faculty. The faculty are very entrepreneurial -- the largest pool of entrepreneurs in our society -- in competing for resources. In major research universities, one third to one half of the total budget is raised by the faculty, through a highly pluralistic system for allocating the resources -- scientific merit playing a large role in the distribution.

If economists want evidence for the advantages of a competitive market-oriented economy, they can find it as easily or more easily in the universities than in the private profit-making sector. Like most human institutions, our universities are not without their defects, but they have served us marvelously well.

The other half of the story concerns human resources. The Great Depression was a great boon to the universities, for it steered into them (as into the Federal government) a great pool of talent that would otherwise have gone in other directions. And for the same economic reasons, they were able to retain much of this talent in their faculties. Added to this was the great flow of European talent sent to our shores by Nazism, and the more recent flow of talent from countries less economically advanced than ours, especially from the Third World -- the Brain Drain.

Federal and State support for the universities allowed them to continue to compete for the best young talent, domestic and foreign, through the decades of the 1950s and 1960s, and into the 1970s.

Now the situation is much more difficult. Fewer faculty openings in the universities and less competitive salaries in comparison with other occupations have led American college students to turn in droves away from academic careers and careers requiring advanced training in science and engineering. This would already have had serious consequences for the universities if substitution of very able foreign students for American students had not put off the day of reckoning.

Today we are continuing to staff our universities with sharp minds principally because many foreign students remain indefinitely or permanently in the United States instead of returning to their home countries. A substantial fraction of all foreign students, and a considerable majority of students from Third World countries, would prefer to settle here, where they have a chance to continue the scientific and scholarly work they do so well.

As long as the balance between returnees and retainees remains somewhere close to fifty-fifty, it is a bargain for both sides. The Third World countries contribute some of their talent to us; we provide superb training for those who return home. There is nothing in the system, however, that guarantees that the balance will be maintained. And meanwhile, we are not succeeding, somehow, in making science and engineering attractive to young Americans.

I have no magical insight into causes or remedies. I have an urge to say to you, "We need more research" -- and undoubtedly we do. Meanwhile, some obvious, and probably sensible, corrective actions have been proposed. We need to strengthen greatly our primary and secondary education. We all know that, but we do not agree on how to do it. We need to make the excitement and joy of science (including social science) more visible to young people -- but that is a task for the scientific community, rather than for the Congress. We need to unhitch more university science careers from the tenure track and provide a greater number of parallel research careers. We need to make sure that the economic rewards are adequate for careers in science and technology, even though we do not believe that dollars are the most important motivators for the best scientists.

Universities and the Economy

We are much preoccupied nowadays, and rightly so, with American competitiveness. We now know that we cannot retain permanently our position of Number One without changing our ways. The game of trying to be Number One is a good game because all can win. All can't be Number One, but all can improve their own and their competitor's productivity by engaging in the contest. We are not (or need not be) poorer because the Japanese or the Europeans are richer. We can feel the greatest pride for having helped bring prosperity to much of the world after World War II, and chagrin that we didn't bring it off for the whole world.

Free Trade in Ideas

But what is the role of the universities in this competition? They are the bastion of free trade -- free trade in ideas. Why should we spend our scarce resources sending ideas to the Europeans and the Japanese with no way of enforcing a payment in return? It is no secret that we have been doing just that in recent decades. (It is also no secret that we were net beneficiaries in the same exchange for a century before our own research establishment gained its present high strength.)

There are several reasons why restricting the flow of ideas is not the solution to the problem. In the modern world, there is no way in which we could prevent the export of the ideas flowing from basic research without interfering in the most serious way with the exchange of ideas among American universities and between universities and American industry. The baby would disappear completely with the bathwater. This is the conclusion reached by the Corson Committee after a very careful study of the current export controls.

Second, the free flow of ideas does not explain why foreign firms have often been more successful in adopting them than American firms. Here the problem lies in the organization and operation of American business, and not in the flow of ideas. I return to what I said earlier about consultants. American firms can benefit from research in American universities only if they organize to do so (as Japanese firms and some European firms have done).

Transfering Research Products to Industry

In America, we have taken some steps in that direction -- the various research consortia that have been established being examples -- but probably not enough steps. In particular, American firms must allocate resources to strengthen their internal R&D capabilities -- not so much their capabilities to *do* research as their capabilities to interact effectively with the universities and to take basic new ideas rapidly through the successive steps that lead ultimately to new products or better manufacturing methods.

Most people who have looked at the problem carefully think that this also calls for considerable internal reorganization of American companies. R&D must be brought into much closer relation with engineering design, and design with manufacturing. Doing that requires, in turn, a considerable restructuring of engineering careers within the company, with far less specialization than holds now. These things will only happen when American industry thinks they need to happen, and I am afraid that there are only limited opportunities for government to play a major role in bringing this about.

University-Business Relations

To the extent that industry is willing and able, what about the universities? In the past decade, we have seen the universities, including the most prestigious ones, quite willing and eager to enter into a variety of relations with business firms for collaboration in research and development. In the course of negotiating and then experiencing these new relations, a number of problems have been identified, the most important of which fall in three categories: the impact of such arrangements on the free flow of ideas, the impact on the balance between basic and applied research, and the question of whether foreign firms should be accepted as partners on the same terms as American firms.

With respect to the first set of issues -- the flow of ideas, most universities are quite sensitive to the need for policies that protect openness. The most important question is not whether proprietary rights can be granted to industry, within the limits of the patent law, but whether it is tolerable to place any restrictions on freedom to publish.

When universities have addressed this problem with care, the usual solution has been to allow some brief publication delays (in order, for example, to permit the filing of patents), but to be very skittish about censorship of research products or review of publications by sponsors. (Of course the same issues arise and have arisen in sponsorship of research by government agencies, especially the DOD.) I'm sure that these issues will call for considerable continuing deliberation, review, and fine tuning, but they seem solvable.

The second set of issues has to do with how far close relations with industry will warp university research in the direction of application. This again is no new issue, nor one that has a simple answer. In some disciplines with which I am familiar -- for example, economics, I would say that pressure to bring research economists into closer contact with the real phenomena of economic life within the business firm can only improve both application and theory. In other fields, too much pressure from application might be harmful.

But we should not start out with the assumption that basic research and application are essentially inimical. Some of the best research problems -- basic research problems -- come from exposure to applications problems in the real world. It is doubtful whether the present exciting developments in the mathematics of chaos would have come about, at least as quickly as they have, without the strong pressure of fields like meteorology and fluid dynamics that badly need a way of dealing with such phenomena as turbulence.

The best way to prevent an undesired warp in university basic research as the result of closer relations with industry is to make certain that there is a steady, and preferably increasing, flow of Federal support for basic research, through such agencies as NSF and NIH, and that not too much of the budgets of those agencies are diverted for the purpose of inducing closer university-industry relations. Poorly designed attempts to encourage application (the NSF RANN effort of the 1970s comes immediately to mind) can be both wasteful of funds and damaging to basic research.

Third and finally, to what extent should foreign firms have the same access to the American universities as domestic firms? The growth of the multinational corporation makes this question especially vexing. If a foreign firm takes an idea from basic research and uses it to generate a new manufacturing activity in the United States, is this good or bad? If an American firm takes an idea from basic research and uses it to generate a new manufacturing activity abroad, is this good or bad? Should American society be subsidizing the basic research in either or both of these cases, or in one but not the other? And if one, which one?

That question is too tough for my weak economist's jaws. Let me see whether I can find a simpler approach. Intrinsically, American firms have easier access to American universities than do foreign firms -- if only they organize to exploit their advantage. They have a language advantage, they have an advantage through larger numbers of alumni, they have an advantage through sharing a common American culture and way of doing business together, they have an advantage through a common patriotism to which they can appeal. On anything like comparable terms, American universities and their faculty members would prefer to build close relations with American companies than with foreign ones.

If this argument is sound (and it is a question of fact that should surely be settled by investigation and not by fiat or authority), then there is no need to limit the right of our universities to enter into favorable relations with business firms, domestic or foreign. If such relations are negotiated from strength -- an appreciation by our universities of what we have to offer -- they will provide resources not otherwise available, and strengthen the universities further. A good exchange is a bargain for both sides.

Of course we must be careful that companies, both domestic and foreign, pay a good price for what they get from their arrangements with universities. A university, like a business firm, has to rest on its own financial bottom and cannot afford to behave like a charitable organization. If universities are careful to see that business, American and foreign, pay for what they get through cooperative arrangements, they can even make a contribution to the faltering trade balance.

It is probably not a bad idea to encourage the universities, individually and collectively, to look at their experiences with their company contracts and other arrangements, and to find out who is benefiting from them and how they are affecting the universities. It is probably premature to make this a subject of legislation or to try to build a link between research support and preference for American firms.

The Social Sciences

In scheduling this hearing, the Committee has expressed some interest in observations on the strengths and weaknesses of the social sciences. I have already commented on the gradually enlarging role of the social sciences in the national structure for providing science advice on issues of public policy. What about the capability of these sciences for providing the advice that is needed?

It is hard for me to avoid advocacy, but if some of my remarks sound self serving, it is because they rest on a lifelong belief that the social sciences have much to contribute to our society, and could contribute much more than they do if they were supported at a more adequate level. I can greatly abridge my comments by referring you to the admirable report on achievements and opportunities in the behavioral and social sciences recently prepared by a committee of the National Research Council. (Gerstein, Luce, Smelser and Sperlich, editors, *The Behavioral and Social Sciences*, Washington: National Academy Press, 1988.)

It is misleading to talk about "hard" and "soft" sciences. In the physical sciences, classical mechanics is hard, but meteorology (e.g., the greenhouse effect) and the theory of high-temperature superconductivity or low-temperature fusion can be (as recent news stories tell us) exceedingly soft. Similarly, in the social sciences, knowledge about the operation of competitive markets or the capacity of human short-term memory is quite hard; but knowledge about how businessmen and consumers form expectations about the future, or about motivations surrounding drug usage can be quite soft.

Since science is always pushing its frontiers, it is always leaving the hard areas behind - they become "common sense" -- and pushing into the soft areas. A science that is hard all the way through is a poor place to do research. In cognitive psychology, for example, thirty years ago we were trying to understand and explain how human beings are able to solve simple puzzles. Today, we think we understand those processes pretty well, so we are researching on how human beings make scientific discoveries. The theory of puzzle solving is hard science, the theory of scientific discovery is still softish science.

To be suitable for research, it is not enough that an area be soft; there should also be some tools for tackling it -- some ideas about the next step. Often data, or ways of getting them, are the key. Inadequacy of basic data is the most serious impediment to social science research in most domains today, and the data are not going to become noticeably better without substantial increases in the level of research funding.

Economics, sociology, and political science need to collect, on a more or less continuous basis, more facts about the way in which our society operates, and the ways in which its human actors behave. Psychology needs increased opportunities to study behavior in the laboratory, and organization theory and business economics need more extensive and detailed observation of what goes on daily in the decision-making work of business firms and government organizations. We particularly need better data about how people and institutions change over time: longitudinal data. I would count sophistication in building and applying theories as among the great strengths of the social sciences today, and the lack of adequate data as among the great weaknesses.

Let me conclude with a comment on research in an area where all of you are expert, and where you know from your own experiences that the "common sense" of media and public can be wholly misleading. Government has a bad press in our society. We praise our democratic institutions, but we can find nothing good to say about politics. There is little realization that democracy and politics are the reverse sides of the same coin -- that a democratic society is a society governed by advocacy, negotiation, consensus building, compromise.

One important area of research in political science is the study of political institutions: building up a realistic picture of how they actually operate and how they would operate if various structural changes were made in them. Even at the modest level of continuing research in this area, political scientists are able to provide a valuable corrective to the sterotyped views of government and politics that are widely current.

They can account for the structure of American political parties -- their conglomerate nature and lack of ideological "purity." They can make reasonably accurate assessments of the effect of registration requirements on non-voting. They can analyze the recruitment of young talent to careers in politics and government. They can throw light on how the political agenda is set.

In sum, they can help us know ourselves as citizens and as actors in the political arena; can provide the realistic knowledge of ourselves that is essential if we are to preserve and improve the democratic institutions that are the foundation of our national life. Surely that knowledge repays many times the small investment -- a few million dollars at most -- that the Federal government makes each year in basic research in political science.

Senator GORE. Well, thank you very much. That is really an excellent statement. And you have given obviously a lot of thought to the issues that we are looking at.

The old science advisory committee was abolished when?

Dr. SIMON. In 1972, probably just after the election.

Senator GORE. Is it fair to say that former President Nixon abolished that committee because he did not like the advice he was receiving?

Dr. SIMON. No, I do not think that is true, although he did not always agree with the advice he was receiving. And I never had occasion to ask the President why he abolished the science advisory board.

I think the impression of most of us was that a considerable factor was the fact that one or two members of that committee felt that it was appropriate both to be a personal science adviser to the President, or a member of the committee, and simultaneously to testify publicly on the Hill in directions which were directly opposite to the direction of the current administrative policy.

Senator GORE. I can see how that might cause some consternation.

Dr. SIMON. Yes.

At the time that was happening, the science committee was, I think, very thoughtfully presenting its views also to the President. And I never got the impression that the President was not wanting to hear those views. He was not wanting to hear them from the Hill in quite the form that he had heard them.

Senator GORE. I see.

But, in your experience, the presidents you have advised have given you the impression that they did indeed wish to hear the advice of scientists and engineers?

Dr. SIMON. I think the proper answer is, at times.

I agree with the comments made this morning that matters of science policy, on the whole, tend to be longer-run kinds of things. They are not usually daily things, although I can recall a few short-run requests that were made.

Furthermore, I do not think we should think of this body as solely an advisor to the President. Perhaps the most important role that the science advisory body played while I was a member of it was as a part of the team of the science adviser, and a part of his continuing connection to the science community.

During the period I was on the committee, we saw the President infrequently and most of our contact with him was quite indirect. But I do not think that diminishes the value of the organization.

Senator GORE. As an esteemed social scientist, you have expressed here your concerns that social science has not been utilized in the same way as the rest of science by policymakers.

The number one priority for our country today is the drug epidemic and certainly we are looking to social scientists for help in designing an effective response to that problem.

But speaking as a United States senator who is very interested, along with all of my colleagues here, in trying to find better answers for that problem, I have had the impression at times that social sciences have not experienced the same exponential growth that we have seen in physics and chemistry and I think the public has that impression as well.

It may be entirely inaccurate, but do you think that impression is one reason why the policymaking process is not as adequately informed by the output of social scientists as by physicists or chemists?

Dr. SIMON. Well, I think we both know, and you have just expressed it, that public perception of social sciences is somewhat different from the public perception of physical and biological sciences.

Social sciences deal with ourselves and our daily lives and we like to think we know a little about them as human beings. Whereas most of us are willing to concede that although we are made of atoms and molecules, still, they are a little more mysterious than our every-day behavior.

That might be an illusion in both of those cases, I do not know, but I think the social sciences have to recognize and respond to the fact that they are perceived differently in the world.

We have words like hard sciences and soft sciences, but I have sometimes a little difficulty as to knowing whether meteorology should be with the first, or whether it should be with the second.

If you judge a science by what it is able to explain and predict, we can find all kinds of softness. What should we say? Cold fusion, for example. You can find all kinds of softness on the physical and biological science side of it.

We also could find——

Senator GORE. Cold fusion may be considered as the power source for the new SDI program, too.

Dr. SIMON. So I do think that these solid things the social sciences can do are not nearly so visible and not nearly as obvious to the public as the things on the natural sciences and we ought to do something about that.

I think also we should not expect social sciences, any more than we expect the natural sciences, to step forward with ready-made solutions to problems, and in my perception one of the most important things to strengthen the ability of the social sciences to do just that would be our willingness to build up more systematically and effectively than we have done the body of basic knowledge and the body of basic data that we have to have in order to do that.

I am not expert on the drug program, but my impression is that longitudinally we know very little about drug usage prior to the present epidemic, the levels of those drug usage, and what effect it had on our society.

We know very little of previous drug epidemics, which there have been in our society and others. If that knowledge were in place we would be in a much better position today to help with the problems. Now, that does not solve the present problem.

Senator GORE. That is certainly a useful point. Now, what about the overall public attitude toward science and technology? You have watched these attitudes change for several decades now.

My own impression is that during the 1970s there was a shift from a view that science and technology was a potential savior to a view that was characterized by rather more skepticism and even hostility as the problems and complications arising out of research in the nuclear field, for example, began to occupy more of the public's attention.

Now I sense the first beginnings of a change back a few degrees toward science as the source of solutions for global climate change problems, for example, giving us more efficient energy, conversion processes, the Mission to Planet Earth as a way to help us understand global climate change, et cetera. Do you sense a change in public attitudes today toward a more positive attitude than a decade ago?

Dr. Simon. Yes, I do sense it, and more reliably than my sense is I think it has been clearly picked up in public opinion surveys of various kinds which have tried to test public views on these matters and there I think we have differentiated those views somewhat more clearly than we have previously.

For example, I think one can distinguish clearly between people's views of science and their evaluations of scientists on the one hand and their views of the effects that technology is having on the society.

Even during the period when people were beginning to have real questions about technology, the prestige of science as an occupation did not apparently suffer during that period very much at all.

On the other hand, I think your description of attitudes towards technology is quite accurate in that we have not returned to a kind of age of innocence where we think all is well and nothing needs to be worried about.

I think our concern, for example, with the environment is a permanent concern and a very valuable concern that we have acquired.

Senator Gore. It has been a long day and the Subcommittee is very grateful for your patience and participation here and your statement adds a great deal, and it is a very good way to conclude the second of these two days.

As I have mentioned before, we are going to continue this inquiry and we will have further announcements about the schedule later on.

But Dr. Simon, thank you very much for coming, and let me thank all of our witnesses and guests today.

The hearing stands adjourned.

[Whereupon the subcommittee adjourned at 12:55 p.m.]

[The following information was subsequently received for the record:]

STATEMENT OF THE COUNCIL FOR CHEMICAL RESEARCH

The Council for Chemical Research is pleased to provide some insights which we consider to be exceptionally pertinent to the Committee's September 28-29 hearings relating to the big picture and major national challenges in setting science policy. We commend the efforts of this subcommittee and its chairman in working to bring national attention to bear on the vital issues facing our country.

The Council for Chemical Research was formed in 1979 to help enhance the U.S. economy, competitiveness and quality of life. We do this chiefly in two ways: strengthening the interactions between academia and industry while carefully avoiding conflicts of interest, and improving support for basic research in chemistry and chemical engineering.

Our members represent the 157 universities where nearly all the U.S. academic research in these fields is done and the 55 major companies which carry out most of the corresponding industrial research.

All the data that we can find show that our chemical companies contribute a much larger share of the research expenditures of pertinent university departments than do any other industries to their pertinent departments.

Necessarily, however, the major source of support for this nation's scientific research in universities is the Federal Government. In the case of chemistry and chemical engineering, the combination of public and private support is uniquely well repaid, for example, by **a net positive trade balance of over $10 billion.** We believe this level to be by far the highest of all the technological disciplines. It is among the reasons why healthy support of basic research in these fields is so important to this nation.

The chemical disciplines stand out in human benefits and in scientific prestige. They stand out in meeting the practical considerations in the National Academy's recent report to the Congress concerning priorities of science.

The spectrum of benefits to our society from chemical processes is astonishing. All food production, nearly all of our energy, most medical advances (including the promise of biotechnology), and modern materials of all types (including the promise of superconductivity) are only a few examples.

Other areas of science and engineering offer similar benefits, though we believe that chemistry's contributions stand alone in sweep and volume. In any event, **the vital role of science and engineering in strengthening the U.S. trade position is**

clear.

Two agencies of the Government are central to assuring vigor in non-defense science and engineering, which is the most directly productive in sustaining competitiveness, the economy, and quality of life. These agencies are the **National Science Foundation** and the **Department of Energy's Basic Energy Sciences. In the hearings on meeting major national challenges, it is essential that the roles of these agencies be recognized.**

The Council for Chemical Research urges that the Committee on Commerce, Science and Transportation and the Subcommittee on Science, Technology and Space, as a consequence of these hearings, **express strong support for appropriation of the full requests for the National Science Foundation's research and education programs and for the Department of Energy's basic energy sciences program.** These are minimal in light of the need and should be fully allowed by the Congress. We urge you to **support the authorized plan to double the budget of the National Science Foundation in the next five years.**

Since the foregoing statements are rather sweeping, let us be more explicit.

It is no longer surprising to state that the United States will compete seriously in trade and will have a satisfactory quality of life only if, among other things, we maintain strong support for research, greatly improve the attracting of bright young people to preparing for careers in science, engineering and mathematics, and assure high quality of such preparation.

There are two overriding reasons which lead to this conclusion: the central importance of new knowledge on which to base technological advances, and enlargement of the pipeline of well prepared bright young people who can discover and use that new knowledge.

As to new knowledge, here are some brief examples of the research opportunities in science and engineering which must be seized if the U.S. is to stay ahead, or even keep abreast of competitor nations. Some of these examples have been in the news, but others may surprise you. It takes years to achieve these things.

New materials having high ratios of strength to weight sometimes outperform steel. Others offer new capabilities in handling information and communication, such as extraordinarily highly packed circuitry on semiconductor chips. All such new materials result from new combinations and manipulations of the chemical [illegible]ments. Chemists and physicists work together to achieve the necessary new understanding.

Superconductivity, at temperatures high enough to open many practical possibilities, depends upon advanced chemical knowledge, both for understanding how to achieve further increases in critical temperature (where the material becomes superconducting) and for producing the new superconductors economically.

Biotechnology, often referred to as genetic engineering, is done mostly by biochemists and biochemical engineers using chemistry. They study the behavior of the genetic molecules known as DNA. Their work involves the discovery and use of chemical understanding to cause plants, microbes, etc., to make products which will enhance agriculture, cure disease, and even catalyze industrial processes.

Hydrogen is not only the cleanest of all fuels. It can also help to ease the greenhouse effect. The possibility of splitting water with sunlight to produce hydrogen will depend entirely on new knowledge and a deeper understanding of photochemistry and catalysis.

Combustion, a chemical process, is our energy mainstay and will remain so for many decades to come. As domestic oil dwindles, and when foreign oil producers return to past pricing habits, improved energy conservation will become even more vital to our economy. An important portion of that conservation will rely on an expanded understanding of the chemistry of combustion processes in order to raise their efficiency while minimizing the production of substances that are harmful to the air that we breathe.

Other examples of research opportunities and frontiers are readably described in the summaries from the National Academy Press: "Frontiers in Chemical Engineering" (1988) and "Opportunities in Chemistry" (1985), copies of which are being forwarded to your committee.

As to the people pipeline, we read much about and are beginning to experience the worsening shortfall in numbers of bright young people who are capable of, and opting for, careers in science and engineering.

Coming needs for well prepared people, in the laboratories which must carry out the research on which the nation's future will rely, number far beyond the count of young people who will be emerging from this pipeline when needed. **A disaster threatens!**

Recent statistics published by the Industrial Research Institute indicate that there are

600,000 scientists and engineers involved in industrial research and development in the United States. Of these 600,000 individuals, 37% are chemists and 13% are chemical engineers. Thus, it is no surprise that we enjoyed a $10 billion net positive balance of trade in 1988 in the area of chemistry. We stand in grave danger of losing this competitive edge, however, because the supply of trained scientific personnel for the chemical industry is dwindling.

We know what the supply of new Ph.D.s in the field of chemistry will be to the year 2000. **Only in the case of a massive economic collapse in the United States would there be sufficient scientific personnel to supply our nation with its needed manpower in the chemical sciences.** By the mid-1990's, Germany will graduate approximately as many German born Ph.D. chemists per year as the United States will produce U.S. born Ph.D. chemists. **Unless we make dramatic inroads within the next few years, we are almost certain to lose our competitive worldwide edge in the area of chemistry.**

It takes, at the very least, a dozen years to attract, educate and train a young scientist or engineer.

We cannot over-emphasize our concern about the level of support for the basic physical sciences. Ph.D. granting institutions in the United States are already experiencing a shortage of qualified faculty in chemistry. This situation will worsen dramatically as the post-Sputnik faculty start to retire in the mid-1990's. Unless major efforts are made to provide increased support, both for fundamental research and for the educational objectives of the basic sciences, we will see a dramatic decline in faculty, students, and the resultant scientists who have made our chemical industry so strong. We can easily slip from a nation that is a world leader in the chemical sciences to one that is no longer a major player in the world chemical market.

The National Science Foundation's education program encompasses a well-planned range of attacks on the problem. They help prepare teachers for the task of catching the imagination of bright youngsters and reinforce this with television programs, museum exhibits, and the modernizing of curricula. They enable undergraduate students, and even high school students, to experience real-world research that is effective in inspiring them to pursue further studies in science. They enable college faculty to strengthen their teaching by doing cutting-edge research. They enable outstanding graduate students to complete their education and training. They attract and enable minorities, women, and disabled students to prepare for careers in science and engineering. They recognize that research is an essential and integral part of education in science and engineering.

The Department of Energy's program in basic energy sciences makes a related attack on the problem. In universities, and in many of the projects at national laboratories, the research depends on faculty-guided efforts of graduate students and postdoctoral people in the many areas of science and engineering which will be crucial to an economic and environmentally acceptable energy supply, and to conservation.

SUMMARY

In the context of science and technology, the Council for Chemical Research draws attention to the close ties among research in science and engineering, education from early school years to postdoctoral training, the U.S. trade balance, the health of the U.S. economy, the health of our citizens, the U.S. quality of life, and the quality of our environment.

Long lead times are necessary for bringing about the benefits of science and engineering and in countering the threats to our competitiveness. **Science and engineering, alone, cannot solve or avoid all the problems, but they comprise an absolutely essential part of the solution.**

As Senator Gore has recently indicated in the AAAS Observer, if we don't turn things around in science and engineering education, the standard of living will fall. At this moment, the major national challenge facing our nation is the strengthening and the rebuilding of this absolutely essential education pipeline in science and engineering.

If we lose our national competitiveness in these essential areas, then all the money spent on other programs of benefit to our society, whether it be in housing, health, or other vital needs, will be greatly reduced in value and effectiveness, and such programs will be endangered.

Mr. Chairman and members of the Subcommittee, the Council for Chemical Research appreciates having the opportunity to express its views.

Thank you.

A STATEMENT ON NATIONAL SCIENCE AND TECHNOLOGY PRIORITIES

We applaud the efforts of Chairman Gore and the members of this subcommittee for initiating these hearings on national science and technology priorities. These hearings come at a crucial juncture. The United States faces ever increasing international competition in both basic and applied research. As you know, the next two years will be critical in shaping and implementing the science and technology initiatives contained in the 1988 Trade bill (P.L. 100-418)--measures which will play a significant role in determining the direction of the federal government's technology agenda.

We submit our views to this hearing as governors who share your recognition of the role of science and technology in both our economic competitiveness and our quality of life. As governors we have led the nation in state science and technology investments. Last year our states invested over 162 million dollars in technology programs. Most of these programs fill the critical gap in our national technology strategy by supporting applied research which bring new products and processes to the marketplace. We believe that these investments are directly related to the fact that manufacturers in the Great Lakes region have exceeded the nation in output over the last two years.

We also present our views as governors who have taken unprecedented steps to work together in responding to our common science and technology challenges and opportunities. Over the last year, we have begun implementation of the Great Lakes Research Network. The Network is one of twelve initiatives contained in an economic development agreement signed in May of 1985. The Network creates formal mechanisms for identifying and collectively supporting world class, commercially relevant, multistate research projects emerging from within our science and technology communities.

We have also acted to create a permanent source of support for research aimed at reducing toxic pollution of the Great Lakes. The Great Lakes Protection Fund will be a $100 million endowment generating $7 to $10 million dollars annually for research and special projects directed at waste minimization and cleanup technologies. The Fund will fill crucial niches between state and federal funding and help foster environmentally sound economic adaptation.

Both the Research Network and the Fund reflect the belief that cooperative science and technology strategies are critical to the future of the common economic and environmental resources over which we share stewardship. It is in the spirit of that belief that we outline our views on federal priorities for science and technology funding.

TOWARDS A MORE RESPONSIVE FEDERAL SCIENCE AGENDA -- THE NEED FOR GREATER BALANCE BETWEEN SUPPORT FOR ELECTRONICS AND ADVANCED MANUFACTURING TECHNOLOGIES

We believe that the most critical step in improving the responsiveness of federal science and technology programs to the competitiveness of the U.S. economy is to adopt greater balance between federal funding for electronics research and advanced manufacturing technologies. As a recent Office of Technology Assessment study on the relationship between technology and the trade deficit concluded, the competitiveness of U.S. manufacturing sectors will have the greatest impact on the balance of trade and hence, the nation's standard of living in the next two decades.

The most fundamental factor in improving the competitiveness of U.S. manufacturing is the adoption of advanced technologies which facilitate more flexible production methods and market responsiveness. The industries and states of the Great Lakes region recognize this linkage between technology adoption in the manufacturing sectors and economic vitality. Each of the science and technology programs in the Great Lakes region contain major initiatives aimed at improving and supporting access to university research by manufacturing firms and industries.

Moreover, the implementation of the Great Lakes Research Network has confirmed our belief that a wide range of collaborative research and development initiatives are underway among basic manufacturing industries.

Federal participation is critical to the long term vitality of these state and industry efforts to improve the technology base of our manufacturing sectors. However, the federal response, has to date, been insufficient, focusing disproportionately on support for electronics technologies.

For example, while the federal government has committed $100 million dollars to the Sematech Consortium, only 15 percent of that level has been committed to the National Center for Manufacturing Sciences (NCMS), the nation's first consortium of basic manufacturers. In addition, efforts in the House of Representatives this session have sought to limit funding for the Department of Commerce's Advanced Technology Program to support for High Definition Television. This action would effectively exclude the nation's basic manufacturing industries from one of the federal governments emerging mechanisms for forging research partnerships.

In presenting this argument, we do not mean to suggest that the United States faces a choice between future competitiveness in electronics or manufacturing. Such a distinction would be similar to the false assertions of the early 1980's that sought to argue that our economic future was one of choosing between a service or a manufacturing economy. For just as services and manufacturing are linked, manufacturing is dependent upon continuing advances in electronics. Manufacturing firms are critical end users of advanced electronics technologies and continued investments in supercomputers are essential to ensure their application to the needs of manufacturers.

Rather we simply seek to ensure that federal science and technology priorities contain greater balance between the needs of these key areas.

STEPS TOWARDS A MORE BALANCED FEDERAL TECHNOLOGY AGENDA

Several actions in the FY 1990 and FY 1991 federal budgets can help create a more balanced and responsive national technology agenda. We recommend the following steps:

- Full Support of the National Institute of Standards and Technology's "Manufacturing Technology Centers Program". This funding is necessary to ensure that full program development occurs at the centers designated in 1988 and to provide for the establishment of additional centers.

- Full funding and a broad mandate for the Department of Commerce's "Advanced Technology Program". It is essential that this mechanism for supporting industrial consortia be responsive to the collaborative efforts of basic manufacturing sectors.

- Increased support for NCMS to facilitate the creation of satellite centers to enable more small and medium sized firms to participate in the collaborative research and technology transfer efforts.

- Support for the creation of an applied bioprocessing program in the Department of Agriculture. This program would fund pilot centers for using biological processes to produce plastics and other products out of corn and other renewable resources.

- Support for the Department of the Navy's "Manufacturing Technology Program". This program is implementing plans to create a center of excellence in composites manufacturing which is essential to our defense and commercial competitiveness in advanced materials.

Two underlying themes are central to this initial agenda for improving the balance between federal support for manufacturing and electronics technologies. First, each of the programs identified incorporate mechanisms for supporting industry led partnerships. Hence, rather than directing investments in technologies, these programs seek to make the federal government a partner in the collaborative efforts of industry. Similarly, each of these programs provide tremendous opportunities for establishing linkages between federal and state science and technology programs and supporting regional cooperation.

TOWARD LEVERAGING A GREATER RETURN ON FEDERAL EXPENDITURES--THE NEED FOR INCREASED RECOGNITION OF STATE INVESTMENT AND COLLABORATION

The Great Lakes boasts among the nation's most prominent researchers and leading research institutions. Eight of the nation's top twenty universities in graduate science and engineering enrollment are located in the Great Lakes region. Additionally, over 100,000 of the nation's 388,681 science and engineering graduate students are enrolled in Great Lakes universities. The region also hosts 52 of the nation's federal laboratories.

Great Lakes industry is also a national leader in research. Seven of the eight Great Lakes states rank among the top twenty states in industrial research and development expenditures. Great Lakes industry invested over $20 billion in industrial research and development in 1985. The region's industry employs over 25 percent of the nation's total scientists and engineers.

To promote the commercial application of the region's research, all eight Great Lakes states have initiated technology programs with a total investment exceeding $716 million since their inception. In 1988, Great Lakes states alone spent nearly $200 million on state technology programs representing about 34 percent of total state technology investment throughout the nation.

The Great Lakes Network encourages and supports the collaborative pursuit of world-class research by these regional resources. Leading researchers, institutions, and facilities are linked without regard to state boundary, but instead by potential contribution to a project. By joining forces the region is not only ensured superior research, but also wider dissemination of the benefits of a project.

A good example of this type of cooperation is the Midwest Plant Biotechnology Consortium. This Consortium has brought together 15 universities, 32 companies, and two federal laboratories in our region. Through extensive interaction and a comprehensive technical review process, Consortium members have developed a ten-year research plan which links federally supported basic research to applied research by industry that will benefit agriculture and agribusinesses in our states.

Despite this regional commitment to scientific inquiry, federal research dollars have increasingly been flowing away from the Great Lakes. The six most western Great Lakes states, which represent 20 percent of the nation's population, receive only about 7.5 percent of federal research expenditures.

STEPS TOWARD CAPITALIZING ON STATE INVESTMENT AND COLLABORATION

- We encourage federal recognition of state research and technology investments in the development of new types of research programs and the awarding of federal research dollars. By recognizing such state commitment, the federal government can build on existing state resources to maximize the return on federal research dollars. Additionally, the federal government will be encouraging further state investment in the nation's science enterprise.

- The federal government should also reward regional approaches to scientific inquiry and technology transfer. By using multistate collaboration as the criterion in warding grants and projects, the federal government will promote excellence in research through the shared use of leading researchers and the most advanced facilities. Fostering cooperation will also ensure that the benefits of federal research are not confined within the borders of a single state.

CONCLUSION

Few aspects of federal policy bear more heavily on our economic future and security than the extent and pattern of our support of research. We commend the work that you have done in this area and look forward to a continuing dialogue on how our region can help the U.S. address the economic challenges and opportunities that lie ahead.